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GEOLOGY

OF THE

TRANSVAAL

G. A. F. MOLENGRAAFF

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GEOLOGY OF THE TRANSVAAL

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GEOLOGY OF THE TRANSVAAL

BY

Dr. G. A. F. MOLENGRAAFF

LATE STATE GEOLOGIST

Translated from the French by

J. H. RONALDSON, M.E.

With Additions and Alterations by the Author

EDINBURGH AND JOHANNESBURG
1904

Edinburgh: T. and A. Constable, Printers to His Majesty

PREFACE TO ENGLISH EDITION

THE English edition of this book is undertaken in the hope that it will bring within the easy reach of many busy men a general sketch of the Geology of the Transvaal. The original was contributed by Dr. Molengraaff to the Geological Society of France while unable to refer to many notes and publications bearing on the subject. Although he has added one new chapter and has more or less corrected and augmented the other chapters of this edition, no attempt has been made to give a full record of the geological researches made in the Transvaal since 1900.

J. H. R.

JOHANNESBURG, *April* 15, 1904.

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GEOLOGY OF THE TRANSVAAL

BY DR. G. A. F. MOLENGRAAFF

Translated from the French[1] by J. H. RONALDSON, M.E.
With Additions and Alterations by the Author.

IN the course of my excursions throughout the Transvaal during the years 1898 and 1899 I made numerous notes on the geology of the country, a résumé of which will be found in this work. The preliminary investigations which it was necessary for me—in my capacity as State Geologist—to make before instituting a systematic geological survey of the country were the origin of these trips.

In 1899 the Volksraad of the South African Republic decided to nominate the staff necessary for the proper work of the Geological Survey Department; but the unfortunate war which has saddened South Africa made the realization of this project impossible.

Geological research in the Transvaal is greatly facilitated by the dryness and the mildness of the climate, the unvarying clearness of the atmosphere, and the scarcity of vegetation. The simplicity of the geological structure in its salient features still further assists the geologist. Nevertheless, certain difficulties counterbalance these advantages; for example, the rock *in situ* is hidden from view over large stretches by recent superficial deposits, such as blown sand, surface limestone, bog-iron-ore, etc., and sections, whether natural or artificial, disclosing the order of the strata are extremely rare. Moreover, and this is perhaps the most serious difficulty, no fossils of a determinable character have yet been found in the sedimentary formations of the Transvaal with the sole exception of that known as the Upper Karroo.

It will therefore be understood why the geological map which accompanies this work ought to be regarded simply as an outline intended to give a general idea of the position and the extent of the different formations which constitute the surface of the country.

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[1] Géologie de la République Sud-Africaine du Transvaal. *Bull. Soc. Géologique France* 1901. 4 sér. Tome i. pp. 13-92. Pls. I. II.

The topography of this map is based on that of F. JEPPE (*Map of the Transvaal, Pretoria,* 1899).[1] The orography, of which no good map exists, has been effected by the aid of various documents; for some districts, such as the Waterberg, I have drawn on sketches made during the preliminary researches of the Geological Survey Department. The geological part is based chiefly on my own investigations, but I have, however, made use of the accounts given by Messrs. D. DRAPER and D. DORFFEL of the districts of Rustenburg and Marico, and, in addition, I have taken advantage of the information available in the different publications referred to at the end of this work, such as the geological map of the Southern Transvaal by Dr. HATCH.[2]

If the Jurassic, Cretaceous, and more recent deposits found near the coast only, be left out of account, the different formations of the Transvaal were until recently generally grouped in the three following main divisions, enumerated in descending order:—

III.—Karroo System;
II.—Cape System;
I.—South African Primary System.

This classification of the geological strata of South Africa had been already adopted by Mr. Bain[3] for the Cape Colony, and for the whole of South Africa by Mr. Schenck.[4] I, for my part, had provisionally adopted the names introduced by the latter author.

Since, however, it has been proved to be doubtful whether the formations constituting the so-called Cape System in the Transvaal may be considered to be equivalent and synchronous to those representing the Cape System in Cape Colony, it appeared advisable to suggest another name for the rocks of the Transvaal, which would not prejudice this question. I therefore proposed in 1902 the term Transvaal System,[1] and this has now been adopted, for instance, by Dr. Hatch in the second edition of his geological map of the Southern Transvaal, recently published.

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[1] F. JEPPE prepared this map whilst in the service of the Surveyor-General of the Transvaal, but died in 1898 before its completion. His son, C. F. W. JEPPE, continued and completed this work, but reaped no benefit from his labour, as he was killed on the battlefield of Spioenkop, January 24, 1900.

[2] F. H. HATCH, **26.** The figures in heavy characters placed after the names of authors refer to the corresponding numbers of the bibliographical list at the end of this work.

The numbers placed between square brackets in the text after the names of properties (farms) are the same as those placed on the corresponding properties in F. Jeppe's map; they are indispensable for a correct appreciation of the text, as a large number of properties in any one district bear the same name.

[3] A GEDDES BAIN, **1**, p. 175.

[4] A. SCHENCK, **56.**

Further, certain formations younger than the Witwatersrand beds, but older than the Black Reef series, are acknowledged now to form a separate system, to which I shall give the name of the *Vaal River System.* Again, the name South African Primary System has given a good deal of confusion, because the word 'Primary' has in English not exactly the same meaning as the word 'Primär' in German, from which language it was derived in this case. By other authors, as by Dr. Hatch[2] in his map mentioned above, the name Archæan System has been used for this group, a term which is also not faultless, because the strata belonging to it, although most probably of Archæan age, have not yet been proved to be such. To avoid misunderstandings, I would suggest to introduce the new name of *Rand System* for this group of rocks, although its application with that of South African Primary System and Archæan System will be adopted promiscuously in this memoir.

Thus the four main divisions recognised in this paper are in descending order :—

IV.—Karroo System;
III.—Transvaal System (Cape System);
II.—Vaal River System;
I.—South African Primary System, or Rand System, or Archæan System.

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[1] G. A. F. MOLENGRAAFF, **42**, p. 74, and **43**, p. 8.

[2] F. H. HATCH, **26**, Geological Map of the Southern Transvaal, with explanatory note. 2nd revised edition, Johannesburg, 1903.

I.—SOUTH AFRICAN PRIMARY SYSTEM, RAND SYSTEM, OR ARCHÆAN SYSTEM

The South African Primary System consists of stratified rocks associated with numerous intrusive masses of granite.

The granites constituting these different masses strongly resemble one another as well as those of Cape Colony.

I have grouped their different types under the name of *Old Granite* to distinguish them from certain granites which play an important part in the central districts of the Transvaal and which are of much more recent origin.

OLD GRANITE.—The old granite is generally a biotite or a hornblende-biotite granite, more rarely a granite with two micas, and occasionally a granite with muscovite. The felspathic element is represented as frequently by orthoclase as by the plagioclases and microcline. Microcline granite[1] is common in the bosses lying between Pretoria and Johannesburg, and also to the west of Klerksdorp.

The old granite and the adjacent schists are intersected by numerous veins of pegmatite exhibiting at several points fine specimens of graphic granite.[2] In Swaziland, near Embabaan, cassiterite[3] occurs in the pegmatite veins, and from the same veins most probably originate the minerals monazite, æschynite, euxenite, and corundum, which are frequently found associated with tin ore in the sands and gravels of the streams in this district.

STRATIFIED ROCKS.—The stratified formations may be divided into two groups.

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[1] For a petrographical description of this rock, see G. A. F. MOLENGRAAFF, **35**, p. 184.

[2] One may particularize the fine graphic pegmatites found near the railway station of Crocodilepoort in the Lydenburg district, and on the Windsor property [190] in the Bloemhof district.

[3] In these veins the crystals of cassiterite assume a rare form; they are elongated considerably in the direction of the edge (111) : (**111**), which gives them quite a monoclinic, and, in the case of twins, an orthorombic appearance. For a description of them, see G. A. F. MOLENGRAAFF, **37**, p. 143, fig. 8, and G. T. PRIOR, **52**, p. 100.

One of these groups is characterized by clastic rocks. It includes phyllites, quartzites, conglomerates, sandstones, clay-slates, cherts, shales, and very rarely limestones. On the other hand, the second group is characterized by the occurrence of true crystalline schists, such as amphibolite, chloritic-schist, sericite-schist, talc-schist, mica-schist, schistose quartzite, etc. Mica-schists are, however, rare in this group. As the hornblende of the amphibolites generally belongs to the actinolite variety, it would be appropriate to give these rocks the name of *actinolite-schists.* Several writers, arguing from the different characteristics of these two groups, have been led to regard the South African Primary System as composed of two distinct formations. Thus, Mr. Gibson[1] distinguishes a lower group formed of gneiss, schists, and granite, and an upper group termed the *lower quartzite and shale group.* Cohen,[2] on the contrary, considered the South African Primary System as one single formation (*Grundgebirge*), and Schenck[3] was of the same opinion, naming it *South African Primary Formation* (*Süd-Afrikanische-Primär-formation*). I am in agreement with the two last authors. It can, in fact, be shown that everywhere the true crystalline schists are confined to the periphery of the granite masses.

The whole of the South African Primary System therefore represents one single series, of which the rocks are greatly modified in their structure by contact-metamorphism, produced by granitic intrusions. In the contact zone the schists show an immense variety of types characterized by the presence of a large number of contact minerals, such as staurolite, andalusite, ottrelite, garnet, corundum, etc.[4]

Nevertheless, in the districts where the South African Primary System has been well developed, as in the Barberton district and in the Witwatersrand, it is preferable to distinguish a lower series confined to the vicinity of the old intrusive[5] granite, consisting of crystalline schists, and an upper series composed of rocks of clastic origin, called the *Barberton series* or the *Hospital Hill series.*[1]

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[1] W. Gibson, **22**, p. 420.

[2] E. Cohen, in P. H. Dahms, **13**, p. 90.

[3] A. Schenck, **56**, p. 225.

[4] A series of these metamorphic rocks collected by Mr. E. Cohen, near Marabastad, in the Zoutpansberg district, has been described by Mr. J. Götz, **23**, p. 163 and following.

Some beautiful types of the metamorphic rocks are those to which I have given the name *corundum-porphyroids* (*roches porphyroïdes à corindon*) and *corundum-schists* (*schistes à corindon*), rocks which are found in several localities around the granitic boss of Vredefort. For their description, see G. A. F. Molengraaff, **35**, p. 198.

[5] Recent investigations tend to prove that in the Southern Transvaal the Rand rocks were deposited on the pre-existing old granite, and, at present, I consider

AURIFEROUS DEPOSITS.—The gold-mines in the vicinity of Barberton, whose working reached its maximum development in 1885 and 1886, the date at which the famous conglomerates of the Witwatersrand were discovered, occur in the rocks of the South African Primary System. The Barberton beds are tilted almost vertically, and are greatly folded; gold is found there widely distributed without being confined to any particular level or to any special rock.

Thus the auriferous quartz reefs are found sometimes in the strata of the Barberton series as is usually the case in the Barberton district; sometimes in the metamorphic and crystalline schists, as in the Forbes-reef mines near Steynsdorp, on the frontier of Swaziland, in the Three-sisters mine to the south-east of Kaapmuiden, in the Woodstock mine near Jamestown, and more to the west, on the same range, in the North Sheba mine; and sometimes even in the granite, close to its contact with the surrounding schists, as in the Cataract mine, a little to the south of the North Sheba mine.

The position of the auriferous beds is intimately connected with the various forms of dislocations which are the result of earth pressure. In fact, the gold is often found in interbedded quartz reefs following the sliding-planes (district of Moodies), at other times the gold-bearing quartz fills crevices and fissures, which generally follow more or less exactly the strike and dip of the strata, while at other times the auriferous quartz forms a ramified network of veins. This last mode occurs at those points where dislocations due to mountain-building movements have been both intense and complicated (in the neighbourhood of the famous Sheba mine). In the whole of these districts the rocks enclosing

---

the question whether this granite must be regarded as intrusive in the oldest sedimentary rocks as doubtful. Direct proofs of the granite being intrusive in the Hospital Hill series are wanting. Possibly the two groups are really of different age, the majority of the crystalline schists being segregatious and alterations by pressure from the granite.

[1] The Hospital Hill beds, on the north of Johannesburg, are the exact equivalent of the Barberton beds. Nevertheless, many geologists have not admitted this identity, and this divergence of views has formerly resulted in the most regrettable confusion.

Mr. SCHENCK considered the Barberton series as a part of his *Swazi-Schichten*, and the Hospital Hill series as the lower part of the Cape Formation.

the auriferous quartz are also more or less impregnated with gold. It results from this distribution of the auriferous veins that in the Barberton district one can trace certain auriferous belts of slight width but of great length. These zones have the same direction as the axis of upheaval or of folding of the hills, and consequently the strike and inclination of the lodes correspond roughly with the strike and dip of the strata of the formation itself.[1]

The auriferous rocks situated on the Klipval farm [33] (district of Piet-Retief), on the Wonderfontein farm [486] (district of Vryheid), in the Murchison Range at Marabastad, at Eersteling (district of Zoutpansberg), as well as the greater part of those in Rhodesia[2] and in Portuguese Manicaland,[3] correspond to the gold-bearing districts of Barberton.[4] In the Hospital Hill series to the north of Johannesburg there occur gold-bearing quartz veins analogous to those of Barberton, but in those discovered up to the present, the gold contents are too low for them to have any economic value, with the exception probably of the Wilgespruit Reef, which in some places at least has been proved to be very rich.

The analogy in the development of certain beds of the South African Primary System in districts of the Transvaal far removed from one another is very remarkable. One group of very characteristic rocks, to which the miners of the Witwatersrand have given the local name of *Hospital Hill Slate,* serves as a leading bed throughout the country by which to recognise the existence of the Barberton series. It is a slaty and quartzitic rock heavily charged with iron, the most typical variety being a banded rock, composed of alternating thin layers of very fine grained white quartzite, black magnetite, and sometimes also red jasper. This rock, observed near Marabastad in 1873 by Cohen,[5] has been described by Götz,[6] who named it *Magnetite-Quartzite-Slate* (*Magnetit-Quartzit-Schiefer*). It was then known among the miners of the Marabastad goldfields under the name of *calico-rock.*

STRUCTURE AND STRATIGRAPHY.—The strata of the South African Primary System are nearly everywhere greatly tilted, folded, and dislocated, and, consequently, the rocks which compose them are highly metamorphosed by pressure. These movements of dislocation have been the result of mountain-forming forces which have been exerted generally from south to north. It follows from this that the strike of the strata in the belts of schists which frequently occur in the area of the old granite, as well as the trend of these belts themselves, has very often a distinct east and west direction. This rule has, however, many exceptions; for example, in the Vryheid and the Piet-Retief districts the direction of the bedding of the Primary System, like that of the mountain ridges of the districts, is sometimes north-west and south-east, and at times north and south. When a mass of granite is entirely surrounded by schists it is noticeable that the strike of the strata is, as a rule, perfectly tangential to the periphery of the mass. If one follows from east to west the belt of primary rocks between the Crocodile River and the Komati River, one sees the strike of the strata, trending at first east and west, bend to the south near Sheba Hill, and, encircling the granite boss of Barberton, again assume an east and west direction on the northern and southern flanks of this boss, in the hills of Noord-Kaap and in those of Moodies; at last the schists disappear with the granite under the sandstones of the Kantoor, which belong to the Transvaal System, and overlie the beds of the South African Primary System unconformably.

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[1] For details of the Barberton goldfields, see A. BORDEAUX, **2**, p. 274 and following.

[2] A. R. SAWYER, *The Goldfields of Mashonaland,* **54.**

[3] A. R. SAWYER, **55.**

[4] A. BORDEAUX, **2**, p. 324.

[5] E. COHEN, **5**, p. 511.

[6] J. GÖTZ, **23**, p. 164.

The panorama to be seen from the summit of the escarpment of Duivels-Kantoor, at an altitude of 5860 feet, is one of the most beautiful geological landscapes that can be imagined. In the foreground, some 1200 feet below, one sees the granite of Barberton, which from this height appears to spread as a plain, but is in reality diversified by numerous sharp-crested hills, formed by the outcropping of diabase dykes intersecting the granite. This granitic area is, moreover, extremely difficult to travel over; it is furrowed by many and deep ravines, locally known as *dongas*,[1] which, viewed from the elevated position of the observer, present the appearance of fallen tree-trunks with endless ramifications. The steep-sided and sharply ridged hills of the Barberton series[2] can be seen, ranged in a semicircle, all round this granite country. The granite and the surrounding schists disappear along a line from north to south beneath the rocks of the Transvaal System, which overlies them with an inclination of about 7° towards the west. The observer on turning towards the west has before him a panorama, differing absolutely from that on the east; to the west there prevails the table-mountain landscape which is so characteristic of slightly inclined sedimentary formations which have been subjected to prolonged erosion.

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[1] A word borrowed from the Zulu language.

[2] These hills follow each other with an extraordinary diversity of shapes, giving the country quite an Alpine appearance.

The same phenomenon is presented more clearly and perhaps in a manner still more pleasing to the eye all round the granite boss of Vredefort (Orange River Colony). This boss, shaped like a huge flatly rounded dome, is half encircled by five ranges of hills in which the strike of the rocks follows a direction sensibly parallel to the periphery of the granite boss. The two ranges next the granite belong to the Barberton series, then come two ranges belonging to the Witwatersrand series,[1] and finally a higher range of hills consisting of amygdaloidal diabases and porphyrites. Standing in the centre of the granite the observer can imagine himself in the arena of a vast amphitheatre surrounded by a semicircle of five gigantic natural walls.

The arrangement of the rocks of the Rand System around the granite boss between Johannesburg and Pretoria, although analogous in principle, is rendered somewhat obscure by the complication of orogenetic phenomena and by the presence of strata belonging to the overlying Transvaal System.

The tilting and folding movements in certain localities seem to have been contemporaneous with the intrusions of the old granite; but, in the great majority of cases, they appear to have been posterior to the intrusions, as may be deduced from the distinctly gneissose and cataclastic structure which is frequently found in the granite near the edges of the masses. The granite and the surrounding schists, both altered by these dynamic forces, are then often blended, and all trace of a line of demarcation disappears.

In the Witwatersrand the beds of the Hospital Hill series are generally free from folding, and in the greater part of the Rand, as for example to the north of the Market Square of Johannesburg, the Hospital Hill beds are represented by a single series of consecutive beds, which has not been duplicated by any phenomenon of folding. At the Witwatersrand the strata of the Rand System are often divided in two groups, the Lower Witwatersrand beds, about identical to the Hospital Hill series, comprising all strata from the Main Reef series downwards, and the Upper Witwatersrand beds, comprising all the strata from the Main Reef series upwards.

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[1] The auriferous conglomerates in these beds are known as the Vaal River Goldfield. They have not up to the present yielded results entirely satisfactory to the prospectors, but their future does not seem to me altogether unpromising.

The groups of strata as set out in the following list can be distinguished in descending order at Johannesburg. Those beds which can be regarded as leading beds or indicators on account of their persistent characteristics are indicated by an asterisk (*) (see fig. 1 and fig. 2).

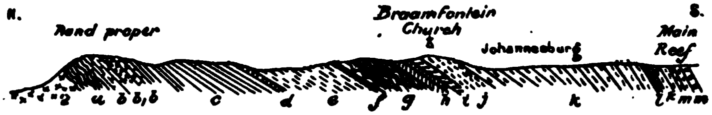

Fig. 1.—Section of the Strata of the Hospital Hill series, in the central Witwatersrand, at Johannesburg, showing the principal leading beds. Scale, 1 : 40,000.

(*m*) Main Reef series.

(**l*) Red-bar, reddish sandstone; a very constant and leading bed near the Main Reef series. Thickness, 3 to 15 feet.

(*k*) Sericitic sandstones, and quartzitic sandstones with some thin beds of clay-slate and conglomerate. Average thickness, 2300 feet.

(**j*) Green quartzite. This quartzite is characterized by a bright greenish colour often changing into pink, especially near the surface exposed to atmospheric agencies.

The varieties showing the brightest green colour are found near the base of this belt: higher up the green colour is often absent, but, nevertheless, very characteristic green varieties are found here and there throughout the belt. Thickness, 600 feet.

(**i*) Yellowish sandstone, mostly in thin layers. Thickness, 100 feet.

(*h*) Red clay-slate. Thickness, 200 feet.

(**g*) Typical Hospital Hill Slate; this rock is often contorted in an extremely curious manner. In some localities, for instance north of Roodepoort, two belts of this typical banded slate are found, composed of one broad series of ferruginous slates, showing two horizons of the typical banded and contorted variety. Sometimes the Hospital Hill Slate loses its typical banded character for some distance, and then merges into an ordinary ferruginous slate. Thickness, 425 feet.

(**f*) Spotted white quartzite known as *speckled bed*. The brown spots are caused by the precipitation of hydroxide of iron in small cavities once filled by fragments of feldspar,[1] now kaolinized and partly removed. This thin layer is very conspicuous all along the Witwatersrand, although in places the specks become rare or are absent altogether. Thickness, 3 to 6 feet.

(*e*) Red or brown ferruginous clay-slate (red shale), with a fairly distinct cleavage parallel or slightly oblique to the line of stratification. This clay-slate is rendered slightly glistening by the presence of very small flakes of muscovite. Thickness, 740 feet.

(**d*) Ripple-marked quartzites: these are white or reddish quartzites. In the central portion of the Witwatersrand this belt of quartzites is very easily recognised through its forming a small unilateral escarpment at the base of which stretches of marshy ground frequently occur. Average thickness, 40 feet.

(*c*) A body of deep red ferruginous clay-slates, known by the name of

---

[1] The colour of this feldspar, where undecomposed, is red.

'black shales' on account of their colour, becoming rapidly black when exposed to the action of the atmosphere. Thickness, 1080 feet.[1]

(*b) Quartzite of the Rand proper. This rock has been subjected to an intense dynamic metamorphism. This quartzitic formation is generally divided into two thick belts of white quartzite, between which is interbedded a sericitic clay-slate with silky lustre, b_1, which is often slightly quartzose and very often neatly plicated. This clay-slate in some localities encloses irregular small veins of pyritic quartz, which have sometimes attracted the attention of prospectors. Average thickness, 500 feet.

(*a*) Schists on the northern slope of the Rand proper; these are sericite-schists and actinolite-schists. Such schists are not infrequently absent, and in this case the quartzite of the Rand proper rests directly on the granite.

2. Old granite.

In spite of the relative stratigraphical simplicity of the Hospital Hill series the lateral pressure acting from south to north has been exerted very forcibly against the boss of granite which has here played the part of a buffer. As a consequence there have resulted numerous dislocations, faults, slidings, and even a scale-like structure. Hence the great majority of faults met with in the workings of the Witwatersrand gold-mines have the character of reverse or upthrust faults. The phenomena which produced the abnormal structure (which, moreover, is not yet entirely explained) of the Hospital Hill series to the east of Johannesburg are, in principle, sliding movements along planes[2] which intersect the planes of stratification of the strata at a very obtuse angle. The result has been a local doubling, or rather a local repetition of a portion of the Hospital Hill beds.

More to the west, in that part of the Witwatersrand which is usually considered to show an undisturbed development, the same faults occur, but, as the planes of faulting here exactly coincide with the planes of stratification, these disturbances have not changed

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[1] In the portion of the Witwatersrand west of Johannesburg lenticular masses of quartzite are frequently found interbedded in the strata of the groups *c* to *h*. They often give rise to additional ridges of considerable length, and complicate not a little the structure of the Witwatersrand in the vicinity of Roodepoort.

[2] It is certainly a very great error to explain this local duplicaton of the Witwatersrand strata, as Mr. GIBSON does, by inversion due to folding. I have never found in any part of the Witwatersrand this series of strata in inverted order as shown by this author in his sections (for example, **22**, fig. 6), and this error arises from his having confounded the green quartzites (fig. 1, *j*) with the quartzites of the *Rand proper* (fig. 1, *b*) and the typical *Hospital Hill Slate* (fig. 1, *g*) with the ferruginous clay-slates (fig. 1, *c*). In the greater part of the Rand the succession of the strata is normal, and neither a duplication nor an inverted order of the strata is found, as indicated by Mr. GIBSON in his section, **22**, Pl. x., fig. 1.

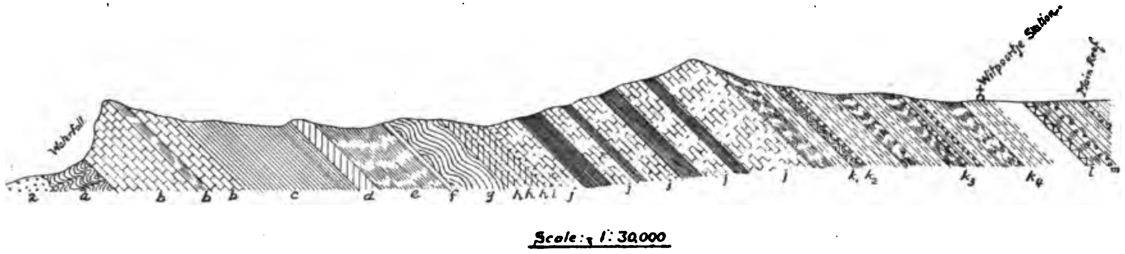

FIG. 2.—Section of the Hospital Hill series in the western Witwatersrand. Scale, 1 : 30,000.

(*m*) Main Reef series. (*l**) Red Bar. (k_4) Sericitic sandstone and thin layers of conglomerate.

(k_3) Red shales, quartzites, and conglomerates alternating, one of the beds of conglomerate being somewhat thicker and more persistent than the others and being known as the 'Government Reef.' Its footwall is invariably a red shale.

(k_2) A layer of conglomerate with an appreciable amount of gold, known as the 'North Coronation Reef.

(k_1) A belt of highly ferruginous and magnetic slates, known as the 'West Rand Slates.' These slates resemble so much the non-typical portions of the Hospital Hill Slates, that they can be, and are often mistaken for them. These slates are very conspicuous all along the Western Rand, but until now they have not been recorded with certainty from any place east of Johannesburg.

(**j*) Green quartzites. The body of green quartzites is very strongly developed in this portion of the Rand, and several layers of shale and slate, and also some thin beds of conglomerate are interbedded with it. The horizon of the North Rand A, or Wilgespruit Reef, is situated near the bottom of this belt. It consists of a mineralized body of fine sugar-grained quartzite, shale, and quartz, and is in some places rich in gold.

(*i*) Schists and diabases. (*h*) Red clay-slate. (h_1) Highly ferruginous red clay-slate.
(**g*) Hospital Hill Slate. (**f*) Spotted white quartzite, *speckled bed.* (*e*) Glistening red clay-slate, *red shale.*
(**d*) Ripple-marked quartzites. (*c*) Deep red clay-state, *black shale.* (**b*) Dynamically metamorphosed quartzite.
(b_1) Sericitic shales, silky and crumpled. (*a*) Sericitic schist and actinolite schist. 2. Old granite.

the normal succession of the strata. Proof, however, is found of movements due to enormous pressure in the frequent *slickensides* and in the minute plicating of the various beds themselves.

AURIFEROUS CONGLOMERATES OF THE WITWATERSRAND.—One series of rocks[1] belonging to the upper portion of the Rand System has acquired an extraordinary celebrity and importance by reason of the famous *bankets* or auriferous conglomerates of the Witwatersrand which they contain. This upper series, which is often called the Witwatersrand series, is composed of sandstones, quartzites, conglomerates, and rarely shales. The sandstones are either friable, and are then usually reddish, as in the *red-bar*, or harder and passing into quartzites.[2] The shales are more or less ferruginous, and generally present a variety of gradations from a clearly schistose type to sandstones. All the rocks of this series, conglomerates as well as the sandstones and shales, are distinguished by the presence of sericite, and assume a more or less schistose appearance. This series of the Witwatersrand attains a great thickness, estimated by Mr. de Launay[3] at about 25,000 feet. The gold is principally found in the conglomerates, sometimes also, and to a less degree, in the quartzites and sandstones. The pebbles of the conglomerates seem to be devoid of gold (this is generally accepted as a fact, but it has never been systematically and thoroughly proved), and from a practical point of view it may be said that the gold is confined to the pyritic cement of the conglomerate or *banket*.

In the central part of the Witwatersrand four series of gold-bearing conglomerates occur in descending order as follows:—

4. The Elsburg series;
3. The Kimberley series;
2. The Bird Reef series;
1. The Main Reef series.

The Main Reef series is the only one of great economic importance; all the gold-mines of the Witwatersrand are found in it.[4]

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[1] I consider it unnecessary to give a detailed description of the gold-bearing rocks of the Witwatersrand because there exist numerous well-known works on this subject. I shall content myself by referring the reader to the works of Messrs. de LAUNAY, HATCH and CHALMERS, and TRUSCOTT.

[2] At a depth all the sandstones get harder and pass into quartzitic rocks.

[3] M. L. de LAUNAY, 32.

[4] It follows from this that I consider the *Botha's Reef* to the west of the Witpoortje fault, the *Kleinfontein* and the *Van Ryn's Reefs* to the east of the Boksburg fault, as the equivalents of the Main Reef series in the central part of the Rand. An exceptional case offers the Lancaster mine, where, besides the Botha's Reef, also the Battery or Kimberley Reef, is worked with profit.

The different series have distinctive features and contain beds sufficiently characteristic to serve as useful leaders in the deep borings that have been carried out to the south of the outcrop of the Main Reef with the object of proving the continuance of this series of rich *bankets* for the working of the *deep levels.* But towards the east and the west, chiefly beyond the great faults of Boksburg to the east, and of Witpoortje to the west, the succession of the auriferous strata, which is typical of the central portion, near Johannesburg, is gradually modified.

The Elsburg series is very different from the others; instead of being composed of a limited number of well-defined conglomerate beds with small or medium-sized quartz pebbles, it consists of a large number of layers of conglomerate blending more or less the one with the other. The pebbles are much larger[1] than in the other reefs, and a great proportion of the rock, considered as a whole, is not quartz, but is derived from various rocks, particularly from quartzites.

On the Witwatersrand the beds of the Hospital Hill Slates have with good reason generally been taken as a starting-point from which to determine the outcrops of the Main Reef, because they are hardly ever hidden from view and are very easy to distinguish. Nevertheless, errors have frequently been committed through overlooking the fact that the horizontal distance between the lines of outcrop of the Hospital Hill Slates and of the Main Reef must vary with the differences of inclination of the intervening strata and according as the thickness of the strata increases or diminishes. Thus, in comparing figures 1 and 2, it is seen that in the Western Rand the distance between the two lines of outcrop must be much greater than in the Central Rand, through the beds of green quartzite being more largely developed in the environs of Krugersdorp than in the neighbourhood of Johannesburg.

The Witwatersrand series outcrops in the following places with characteristics very analogous to those which it presents on the Witwatersrand[2]:—

1. In the environs of Heidelberg, where the strike and dip appear to be largely influenced by two bosses of granite, one

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[1] In the other reefs, for example in the Main Reef, large pebbles are not entirely wanting, but are rare. Thus I have received through the kindness of Mr. Walker, late Inspector of Mines, some pebbles 10 inches in diameter, coming from the Main Reef in the Langlaagte mine.

[2] The conglomerates found on Zwartkop, west of the granite boss which lies to the north of the Witwatersrand, may be mentioned here, although they have not yet attracted much attention.

occurring east of Heidelberg, the other more to the south near the Vaal River, the latter being entirely hidden from view by the strata of the Upper Karroo System in the South Rand Coal-field.[1] The strata appear to dip everywhere away from these bosses of granite. The mines on these portions of the Witwatersrand series are known collectively as the Heidelberg Goldfields.

2. In a semicircle round the granite boss of Vredefort; the beds are tilted vertically or even tilted over with an inclination towards the granite; this is the *Vaal Goldfield* (Pl. II., Section 1);

3. In the neighbourhood of Klerksdorp and of Rietkuil; constituting the *Klerksdorp Goldfields.* Here the strike of the strata, as well as the dip, varies greatly. The geology of the Klerksdorp district is not simple, and is rather insufficiently known. Both the Witwatersrand beds and the Vaal River System have a large development here.

In all these localities auriferous conglomerates occur, the best and richest of which are regarded, with more or less reason, as the equivalents of the Main Reef series on the Witwatersrand.

If one examines on the map the strike and the dip of the strata of this series in the different localities just indicated, and if one has regard to the fact that the inclination of the strata generally lessens at a certain distance from the line of outcrop and finally acquires for the Witwatersrand series, considered as a whole, an average value of about 25° to 30°, as ascertained to the south in boreholes at depths of more than 4000 feet, one finds evidence that the Witwatersrand series, in the south of the Transvaal, forms a curved syncline or trough, *the Basin of the Witwatersrand.*[2] The limits of this syncline have been followed beyond the lines of visible outcrop by means of boreholes sunk through the overlying formations. Thus its existence has been proved beneath the Dolomite series and beneath that of the Black Reef, both of which belong to the Transvaal System; it has also been found in several places under the beds of the Karroo System, and even under the Transvaal and Karroo Systems superimposed, as to the east of Boksburg (Heidelberg district).

The detailed stratigraphy of the auriferous Witwatersrand series being somewhat complicated and still little known, it is not astonishing that some writers consider these a distinct formation lying uncomformably on the Hospital Hill series. My investigations have not confirmed this opinion. The auriferous strata of the Witwatersrand appear to be everywhere comformable with those of the Hospital Hill series, besides, researches made in different districts of the Transvaal have shown that the auriferous strata of the Johannesburg district ought to be regarded as intimately connected with the other divisions of the South African Primary System, of which they form, locally at this point, the upper part. Besides I have found in the Vryheid district,[1] on the farms of Rondspring [137], Dipka [590], and Mahlone [524], and on the Denny-Dalton Company's property, true *bankets* or auriferous conglomerates and other deposits that cannot be distinguished from those of the Witwatersrand series (see fig. 3). The auriferous *bankets* are there interstratified conformably with the beds belonging to the Barberton series which have absolutely the appearance of the rocks of the Hospital Hill series near Johannesburg. Nevertheless, it must be acknowledged that in the Elsburg conglomerates in the upper portion of the Witwatersrand series there are frequently found pebbles of rocks apparently belonging to the Hospital Hill series, which would go to prove that the latter strata had already been exposed to the agencies of erosion and denudation when the Elsburg conglomerates were being laid down. It is thus possible that the whole of the strata from the base of the Hospital Hill series up to the Elsburg beds, although arranged in apparent conformability, does not represent an absolutely uninterrupted series, and that there may exist an unconformability between the Witwatersrand beds as a whole or more probably between its upper part only and the Hospital Hill series.

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[1] A. R. Sawyer, 53.

[2] G. A. F. Molengraaff, 35, p. 177.

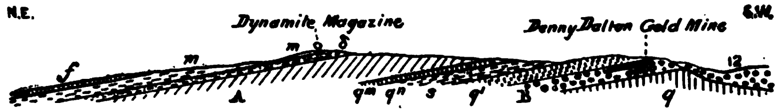

FIG. 3.—Section through the Denny-Dalton gold-mine (Vryheid district) showing auriferous conglomerates (*Bankets*) identical with those of the Witwatersrand, interstratified with beds of the Barberton series (Hospital Hill series).—Scale, 1 : 15,000.

12. Dwyka conglomerate; *f*, Ferruginous schists, thickness, 10 feet; *m*, Schists and slaty schists with muscovite, thickness, 61 feet; δ, Diabase, thickness, 30 feet; *A*, Shales, thickness, 206 feet; *q'''*, Quartzites, thickness, 20½ feet; *q''*, Hospital Hill slates and jaspers, thickness, 51½ feet; *s*, Satiny schists, thickness, 41 feet; *q'*, Quartzites, thickness, 59 feet; *B*, Banket and quartzite, thickness, 103 feet; *q*, Schists and quartzites.

VARIOUS ORE DEPOSITS.—Besides gold, the principal deposits of which have just been mentioned, there are also some ores of other metals found in the South African Primary System, which in the nature of their occurrence closely resemble that of the auriferous deposits, being generally found in veins which have the same strike and dip as the enclosing strata.

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[1] G. A. F. MOLENGRAAFF, 39, p. 37.

Thus, cinnabar is found in a sericitic schist in the Lomati valley; stibnite in the amphibolites near Forbes Reef in Swaziland, near the Komati River to the north of Steynsdorp, and in the Gravelotte mine near Leydsdorp, where free gold is associated with the stibnite. Well-crystallized crocosite is found in a contact vein associated with a diabase dyke which intersects the staurolite schists of Darkton, in Swaziland.

Some interesting deposits of copper ores and native copper have been discovered in an amphibolite,[1] which forms narrow belts in granite on the farm of Goudhoek [498] in the south of the Vryheid district. Further, the mines of auriferous quartz are often comparatively rich in iron and copper ores, as, for example, on the farm Doornhoek [340], Vryheid district; in the gold-mines of Noord Kaap to the north of the granite boss of Barberton; and in the Sheba Queen mine, near Steynsdorp, where a reef has been worked which, although it has not been closely studied, seems to be a true fissure-vein.

ERUPTIVE ROCKS.—The rocks of the South African Primary System and the old granite are intersected by numerous dykes of eruptive rocks, for the most part diabases. In the stratified rocks bodies of diabase, often of great thickness, are frequently found, either as sheets interbedded conformably between the strata of these rocks, or as dykes cutting across them. Besides diabase also acid felsitic types are found. A granophyric structure is common in several of these igneous rocks. Some dykes and intrusive sheets found in the Hospital Hill series at the Witwatersrand are much altered by decomposition and pressure, and often so closely resemble indurated shales, that they are mistaken for them.

OUTCROPS AND AGE.—The rocks of the South African Primary System crop out throughout the whole of the *Low-veld* or low country, that is, in the entire low-lying stretches of ground between the eastern escarpment of the *High-veld* or high plateau of the Transvaal and the eastern frontier, except over a belt of an average width of ten miles along the frontier, consisting of rocks belonging to the Upper Karroo System and situated on the the eastern side of the *Great Eastern Fault* (Pl. II., Section 2).

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[1] It is quite possible that this amphibolite is nothing else than a uralitized diabase highly altered by pressure.

In the Vryheid district the Archæan System is partly covered by deposits of the Karroo System. In the Zoutpansberg district it occupies vast stretches, but the geology of this district is still very little known. It is the same in the districts of Wolmaransstad and of Bloemhof, in the south-west of the Transvaal, where the Rand System crops out largely, but is hidden from view at many points by deposits of the Vaal River System, of the Lower Karroo, and by more recent surface deposits. Over the whole of the central part of the Transvaal the Transvaal System overlies the Rand System unconformably, and the latter crops out only where the former is entirely denuded, that is, in the large area where the gold-mines of Johannesburg are worked, in the neighbourhood of Heidelberg, to the south-west of Krugersdorp, and around the large granite boss of Vredefort (Plate II., Section 1).

The age of the South African Primary System in the Transvaal is unknown. But since we know that it underlies uncomformably the Vaal River and again the Transvaal System, and that most probably the latter is older than the Cape System in the Cape Colony, in which the Bokkeveld beds are known to be of Devonian age, the rocks of the Transvaal System must be pre-Devonian, those of the Vaal River Systems still older, and our Rand rocks older again; hence the supposition that they really may be Archæan appears justifiable.

II.—VAAL RIVER SYSTEM

Amygdaloidal Rocks of the Witwatersrand.—The Witwatersrand series, which we consider as representing a great local development of the upper part of the South African Primary System in the south and south-west of the Transvaal, is largely covered by enormous flows of diabasic and porphyritic rocks. These flows cover a very large area, resting on the sandstone and auriferous conglomerate series, in the Klipriversberg to the south of Johannesburg, in the neighbourhood of Heidelberg, in the auriferous zone around the granitic boss of Vredefort, and in the neighbourhood of Klerksdorp. In the Klipriversberg, where the thickness of this effusive series exceeds 2500 feet, it consists in its lower portions of amygdaloidal diabases resting on the Elsburg beds; higher come the porphyries, which are again overlain by amygdaloidal diabases. The same succession is repeated in the effusive series which encircles the Vredefort granite boss. In the south-west of the Transvaal, where the bedding of the South African Primary System is nearly horizontal, these amygdaloidal diabases stretch over a very large area.[1] Quartz-porphyries (palæo-rhyolites) are found there interstratified between amygdaloidal diabases and melaphyres, proving that in this region basic and more acid rocks have been alternately brought to the surface. These quartz-porphyries[2] are very fine rocks that had already attracted the attention of the early explorers, such as Hübner[3] and Cohen. They withstand denuding influences to a high degree, and as a consequence form elevated ground or groups of hills where they occur, as in the Makwassiebergen (district of Wolmaransstad) and in the hills near Klerksdorp, along the Schoonspruit.

These amygdaloidal rocks and porphyries of the Witwatersrand or 'Klipriver amygdaloids,' as they are generally locally called, have been considered to represent the uppermost division of the Witwatersrand beds, and, together with silicified tufas and cherts occurring in connection with these in the districts of Klerksdorp and Wolmaransstad, were, in the original French edition of this book, placed by me at the top of the South African Primary System or Archæan System, although I admitted their true position to be doubtful. Since then, however, I have been able to prove, and my opinion has been confirmed by several geologists,[1] that these rocks, together with several others of doubtful correlation, all belong to one hitherto unrecognised formation, which is younger than the Witwatersrand beds, but older than the Black Reef series.

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[1] Mr. E. Cohen, in 1873, had already remarked with good reason that these amygdaloidal diabases of the Vaal were older than the diabases of the Karroo System. See E. Cohen, **9**, p. 210.

[2] For a description of their petrography, see P. Dahms, **13**, p. 108; and G. A. F. Molengraaff, **35**, p. 213.

[3] A. Hübner, **30**, p. 82.

Up to the present these formations have been called 'New formation,' also 'Ventersdorp beds,' but I shall comprise them all under the name of *Vaal River System.* I consider this name a very adequate one, as the Vaal River has cut its bed in rocks belonging to this system almost uninterruptedly from Klerksdorp down to its confluence with the Orange River, *i.e.* over a distance of more than 240 miles. Moreover, as early as the year 1878 Cohen,[2] who described the peculiar amygdaloidal rocks of the Vaal River, and followed them over a distance of about eighty miles, has characterized them by the name of 'Vaalgesteine.'

GENERAL CHARACTER AND STRATIGRAPHY.—Igneous rocks play a most prominent part in the Vaal River System, in fact I believe that without exaggeration one might estimate about eight-tenths of the entire complex to be of igneous origin. The principal rocks are amygdaloidal diabase, diabase, diabase porphyrite, quartz porphyry, felsitic amygdaloidal rocks, tufas, silicified tufas, chert, igneous breccia, shales, shaly conglomerates, very coarse conglomerates or boulder beds, grits and sandstones. The cherts are generally thinly laminated and consequently present a banded appearance, which is very characteristic of this rock. In some places the cherts are silicified tufas, in others their mode of formation is still unknown; several of the shales are altered igneous rocks, and the cement of a part of the conglomerates is equally of igneous (tufaceous) origin; then the only purely non-igneous rocks are grits, sandstones, and some conglomerates or boulder beds and shales. The strata of this formation are, as a rule, less tilted than those of the Witwatersrand beds. Their unconformable position on the Lower Witwatersrand beds can be seen in several places, as, for instance, near Ventersdorp,[1] on Goedgevonden [377] in the Potchefstroom district,[2] and in the neighbourhood of Zwartkop [82] in the Krugersdorp district. This unconformability is very striking and well exposed on the farms Schietfontein [122] and Syferfontein [504], west of Klerksdorp, where igneous breccia, sandstone, conglomerate, and chert of the Vaal River System in well-defined horizontal strata form a perfectly flat-topped kind of table mountain resting on ferruginous shales and quartzites of the Lower Witwatersrand beds or Hospital Hill series, which strike N. 60° W., dip 60° S.W., and form a bold ridge trending in the line of strike. Equally fine is a section obtainable on Nieuwjaarsfontein [216] and Abelskop [152], in the Bloemhof district, where the Harts River has cut through a plateau of horizontal strata, composed of chert, quartz porphyry, and amygdaloidal rocks belonging to the Vaal River System, and has exposed in its broad valley the underlying rocks, granite, and stratified rocks belonging to the Hospital Hill series, the latter being much contorted, but with a general N.W.-S.E. strike and a nearly vertical dip. The unconformability of the Vaal River System on the Upper Witwatersrand beds has not yet been shown by direct evidence, but can be deduced from the fact that boulders of *banket* occur very frequently in the conglomerates of the Vaal River System, and sometimes these boulders of auriferous conglomerate are so plentiful that prospecting work has been carried out on them for gold, as has been the case in the boulder beds of Zendelingsfontein [88] in the Wolmaransstad district,[3] and in those near Ventersdorp.[4] The unconformability of the strata of the Vaal River System with the overlying Black Reef series is in some places exceedingly well marked, as is the case at Kromdraai [71] (see fig. 5 on page 29), and at Rietfontein [286] in the south of the Pretoria district; in other places these strata lie apparently conformably under the Black Reef, especially when both formations are horizontal or only tilted at a slight angle.

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[1] G. A. F. MOLENGRAAFF, **45**, p. 68; F. H. HATCH, **28**, p. 95; G. L. CORSTORPHINE, **12**, p. 99.

[2] E. COHEN, **6**, p. 52; and **9**, p. 210.

North of the Witwatersrand this formation occurs at a few places only, and the farm Tweefontein [76] is the most northern locality where it is at present known to exist. In the districts of Potchefstroom, Krugersdorp, and Heidelberg, the Vaal River System is represented over vast areas by the Klipriver amygdaloid, and is found in detached, though often extensive patches; but towards the south-west the formation covers a more continuous area. It outcrops over a great portion of the districts of Lichtenburg, Wolmaransstad, Bloemhof, and Hoopstad. The chert of Hartebeestfontein[1] (624), the quartz porphyries of the Klerksdorp hills, and the Vaal River amygdaloids belong to it. From Klerksdorp down-stream I followed the rocks of the Vaal River System along the Vaal River to beyond the mouth of the Harts River, although the rocks of the Lower Karroo or recent fluviatile deposits often hid them from view. From Stow's manuscript map we may expect them to be found along this river as far as its confluence with the Orange River. Again, the melaphyre, quartzite, and quartz-porphyry struck in the rock shafts of the Kimberley mines under the beds of the Lower Karroo belong to the Vaal River System. The exact correlation of the rocks belonging to the Vaal River System will not only greatly elucidate the geological structure of the South-west Transvaal, but will also facilitate finding a connecting link between the results obtained by geological researches made in the Cape Colony and those obtained in the Transvaal.

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[1] F. H. Hatch, **28**, p. 97.

[2] G. S. Corstorphine, **3**, p. 100.

[3] G. A. F. Molengraaff, **35**, p. 240.

[4] F. H. Hatch, **28**, p. 95.

One weak point, however, exists in this correlation—viz. the position of the rocks of the Vaal River System with regard to the uppermost division of the Witwatersrand beds. Undoubtedly, as has been mentioned above, the Vaal River System is unconformable with the Lower Witwatersrand beds, and the presence of boulders of *banket* in the conglomerates of the Vaal River System proves that this must be unconformable with at least a portion of the Upper Witwatersrand beds, but to which is unknown. In all places where the contact between the Elsburg beds (taken here as the uppermost division of the Upper Witwatersrand beds) and the overlying rocks of the Vaal River System is exposed, a clear conformability has until now been observed. But, on the other hand, the occurrence of pebbles apparently identical with fragments of Hospital Hill slate (see page 16) in the Elsburg beds may lead to the supposition that the Elsburg beds cannot be a portion of an uninterrupted succession of conformable strata from the Hospital Hill slates upwards; and, finally, there is an undeniable resemblance between the conglomerates of the Vaal River System in some places and the Elsburg beds. All these facts combined lead to the question: Is it not possible that the Elsburg beds, though at the Witwatersrand apparently conformable with the entire group of Upper Witwatersrand beds, are in reality unconformable with the lower division of the Upper Witwatersrand beds, and do they not rather belong to the Vaal River System, representing in the Witwatersrand area the lowermost portion of the Vaal River System conformably underlying the Klipriver amygdaloid? It cannot be denied that, by assuming the Elsburg beds to belong not to the Witwatersrand beds, but to the Vaal River System, several stratigraphical difficulties can be solved comparatively easily.

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[1] The siliceous strata of the Vaal River System sometimes closely resemble the beds of hornstone, which are very common in the dolomite series of the Transvaal System. In 1890 this similarity led me into error in believing that I had found the dolomite formation in the cliffs in the neighbourhood of Hartebeestfontein (624), district of Potchefstroom, which consist of these siliceous strata; see **35**, p. 261.

But, on the other hand, difficulties stand in the way of this interpretation, the chief being involved in this question: Admitting an unconformability between the upper and lower division of the Upper Witwatersrand beds, where does it begin? At the base of the Elsburg series, or still lower down, perhaps at the base of the Kimberley, where similar pebbles occur as in the Elsburg series? No facts decisive in one or the other direction are as yet recorded, and one has to wait for fresh investigations in order to obtain a solution.

ORE DEPOSITS.—No ore deposits have as yet been discovered in the Vaal River System. Besides the fruitless searches already mentioned, and those made in the boulder-beds and conglomerates of the district of Hoopstad ~~and~~ on Zoeten Inval [268] and adjoining farms, prospecting for gold has been carried on with very poor results. On Zoeten Inval these conglomerates offer some resemblance to the Elsburg beds; they are overlain in conformable succession by flows of amygdaloidal diabase, and rest conformably on beds of laminated chert.

AGE.—As to the age of the Vaal River System we only know that this is older than the Transvaal System and younger than the South African Primary or Rand System. The unconformable position of the Vaal River System on the Rand rocks proves, however, that a certain time must have elapsed after the close of the Rand epoch before the strata of the Vaal River System were deposited; and, again, the great denudation and destruction that the beds of the Vaal River System have undergone themselves before the Black Reef series was deposited unconformably upon them, leads us to believe that a considerable gap must exist between the periods of the formation of the strata of the Vaal River System and those of the Transvaal System.

III.—TRANSVAAL SYSTEM (CAPE SYSTEM)

The five following divisions, in descending order, constitute the Transvaal (Cape) System:—

5. Waterberg Sandstone series;
4. Bushveld Plutonic series;
3. Pretoria series;
2. Dolomite series;
1. Black Reef series.

Over a very large part of South Africa there is found lying unconformably on the South African Primary System a very thick series of beds, which are divisible into three clearly defined groups. In the Cape Colony they are:—

3. Witteberg beds;
2. Bokkeveld beds;
1. Table Mountain Sandstones.

In the Transvaal they are:—

3. Pretoria series;
2. Dolomite series;
1. Black Reef series.

The Bokkeveld beds are the only rocks anterior to those of the Karroo in which fossils have been found (marine organisms belonging to the Lower Devonian).

Researches made before 1899 by the Geological Departments of the Cape Colony and of the Transvaal led to the conclusion that these three groups might probably be correlated in the two countries. Consequently, the great gap which causes the Table Mountain sandstones to rest unconformably on the Malmesbury schists, would be really identical with that which places the beds of the Black Reef series unconformably on the Primary System of the Transvaal. However, perfect parallelism remained far from being established between the subdivisions of the Cape System in the Cape Colony and those of the supposed corresponding system in the Transvaal. Certainly there exists a striking resemblance between the sandstone of Table Mountain, in Cape Colony, and that of the Black Reef series, in the eastern part of the Transvaal; but on comparing the other groups, the Bokkeveld and the Witteberg beds on the one hand, with the Dolomite and the Pretoria beds on the other, it is evident that nearly all petrographical analogy is wanting.

Later researches, made in 1899 by the Geological Survey of Cape Colony, have brought us much nearer to a solution, which, however, diverges from the opinions previously expressed.

Messrs. Rogers and Schwarz lately informed me that, according to their investigations in the Cape Colony, the relationship of the Dwyka conglomerate to certain of the ancient rocks of Prieska, which are probably the equivalents of the rocks in the Transvaal hitherto correlated to the rocks of the Cape System in the Cape Colony, is such as to make it probable that these ancient rocks are older than the Table Mountain sandstone.

This opinion, together with the discovery of the Vaal River System in the Transvaal, has forced me to the conclusion that the name 'Cape System' should be given up for the series of formations mentioned above, in favour of the new term *Transvaal System*, which is now proposed for this group of rocks.

1.—BLACK REEF SERIES

The Black Reef series is composed of dark quartzite, arkose, sandstone, clay-slate, greywacke, and auriferous conglomerate. It is very variable in thickness. To the north, in the mountains of Makapan and of Chunie, it may be estimated at 1640 feet, and at Lydenburg it attains an average of 1000 feet; towards the south its thickness decreases to about 200 feet at Duivel's Kantoor. To the south of Pretoria, in the Witwatersrand and at Klerksdorp, it does not exceed 100 feet, and around the Vredefort boss its development is very slight, or even entirely wanting. Again, the Black Reef series is not seldom merely represented by one or more layers of quartzite or quartzitic sandstone interbedded in the lowest portion of the dolomite series, with which the Black Reef series is always intimately connected. Such is, for instance, the case in both the areas known as the West Rand Extension and the East Rand Extension, as has been proved by boreholes sunk on Ventersport [27] and adjoining farms in the West Rand and on Klipfontein [206], Rietkol [543], and other farms in the East Rand.

The Black Reef series has received different names, according to the different regions in which it occurs, because it was not recognised for a long time that these various groups could be correlated.

In 1898 I extended the name of *Black Reef series* to all those beds which are identical throughout the whole country.[1] Till then this name had generally been applied only to the portion of this formation occurring in the Witwatersrand syncline to the south of Johannesburg. At Klerksdorp it was designated by the name of *Boschrand series,* to the north of the Witwatersrand it formed the *Kromdraai series,* whilst in the eastern part of the state it was called *Kantoor Sandstone* and *Drakensberg Sandstone.*[2]

STRATIGRAPHY.—The line of outcrop of the Black Reef sandstones, although generally rather sinuous, is generally very easy to follow on the surface, because these rocks form often a slightly elevated and more or less wooded escarpment in contrast with the plains, which are nearly everywhere devoid of trees. The numerous transverse faults which divide up this escarpment are revealed by gaps and by corresponding fractures. On the northern slope of the body of granite between Johannesburg and Pretoria, where the ground has a general fall to the north, the outcrop of the Black Reef sandstone, which rests on this granite, forms a natural wall utilised by the farmers for the storage of water. By constructing dams across the gaps which are the results of faulting, they collect large quantities of water, and are thus enabled to irrigate methodically the arable land lying low.

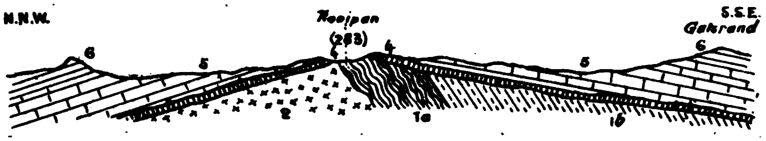

FIG. 4.—Ideal Section of the Anticline of the Transvaal System at Wonderfontein to the south-west of Krugersdorp (after D. Draper, *Trans. Geol Soc. of South Africa,* ii. part IV., 1887).

6, Pretoria or Magaliesberg series; 5, Dolomite series; 4, Black Reef series; 2, Old Granite; 1*b*, Sandstones and Conglomerates of the Witwatersrand; 1*a*, Barberton or Hospital Hill beds.

The Black Reef series being laid down unconformably on the South African Primary System (fig. 4), rests, according to the point considered, on rocks differing greatly from one another, belonging either to the latter or to the Vaal River System. Thus to the south of Klipriversberg the Black Reef is found overlying the Witwatersrand amygdaloid; in the Potchefstroom district it rests on different beds belonging to the Witwatersrand series or to the Vaal River System; then in the neighbourhood of Krugersdorp it overlies the auriferous beds of the former series. To the north-west of Krugersdorp the Black Reef series is seen to rest on the Hospital Hill series, the strata of the two systems having strikes at right angles to one another. More to the north at the Kromdraai mine it lies uncomformably on schistose conglomerates, which belong to the Vaal River System (fig. 5). Still further, to the south of Pretoria, the Black Reef series is seen resting directly on the granite. In the eastern escarpment of the high plateau of the Transvaal, as well as in the mountains of Makapan and of Chunie, sometimes the granite, sometimes the crystalline schists or strata of the Barberton series, are found in evident unconformity beneath the Black Reef series (see fig. 10 and Pl. II.).

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[1] See G. A. F. MOLENGRAAFF, **37**, p. 124.

[2] J. G. BOUSQUET, **3**.

AURIFEROUS BEDS.—Quite at the bottom or near the bottom of this series there occur one or several beds of conglomerate more or less auriferous. The term *Black Reef* was employed in the first instance by the miners of the Rand to designate this auriferous conglomerate, which on the outcrop was found to be of a *darker* colour than the other conglomerates already encountered lower than the amygdaloidal diabases of the Klipriversberg. Later, it was proved that this conglomerate occurs nearly constantly at the base of the Black Reef series, but that it is not always gold-bearing. Its characteristic is that it encloses pebbles of a greater number of different rocks than the auriferous conglomerates of the Witwatersrand series. The Black Reef has been worked to the south of Klipriversberg, in the Boschrand near Klerksdorp, and at Duivel's Kantoor in the Lydenburg district. These operations have not been successful, chiefly on account of the unequal distribution of the gold in the conglomerate. Rich or very rich zones (*chutes*) alternate with barren parts of great extent.

The strike and the dip of the Black Reef strata to the south of Johannesburg are found to be accidentally nearly the same as those of the sheet of amygdaloidal diabase and of the underlying Elsburg sandstones; an occurrence which has greatly retarded the determination of the exact position of the Black Reef and of the whole of the Transvaal System in the parts associated with the gold-bearing formation of the Witwatersrand. This is one of the causes which induced geologists formerly to regard the auriferous sandstones of the Witwatersrand as the lower part of the Cape System, correlating them with the Table Mountain sandstones.[1]

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[1] In 1890 I made the same error by including the Witwatersrand series with the amygdaloidal diabases and the Black Reef series, then called by me the

On the contrary, the gold-bearing series of the Witwatersrand is a part of the South African Primary System, and is much more ancient than the Transvaal System; the apparent conformability of the Black Reef with the Witwatersrand series near the Klip River is purely accidental and local; besides, in the neighbourhood of Krugersdorp the sandstones and the conglomerates of the Witwatersrand are seen to disappear under the sandstone of the Black Reef, with which they are, at this point, evidently uncomformable.

Dr. Hatch, to whom we owe the best geological map[1] of the southern Transvaal, gives the position of the Black Reef series in the Witwatersrand syncline correctly; and in the recent second edition of his map he rectifies the omission of the same series under the Dolomite to the north of Krugersdorp and beyond on the northern slope of the granite formation between Johannesburg and Pretoria, where the Black Reef series crops out between the Dolomite which covers it and the underlying granite. The conglomerates, at these points, are poorly developed at the base of the series, and do not contain more than traces of gold. Dr. Hatch regards the Black Reef series as a special secondary deposit of matter broken down from the older formations, and it appears to me only natural that towards its base conglomerates rich in gold should have been found at Klipriversberg, seeing that the gold-bearing beds of the Witwatersrand crop out in the vicinity; and that, on the other hand, there were laid down at the same time on the granite boss between Johannesburg and Pretoria deposits practically devoid of gold but with well-developed strata of arkose.

In the Lydenburg district there occurs in the sandstone of the Black Reef series, locally known as the *Drakensberg Sandstones*, an auriferous bedded vein containing quartz and iron ore. This vein, which is interbedded between two layers of sandstone, is worked in several localities, for example, on the farm of Erasmushoop, where it is called the *Sherwell Reef.*[2]

Boschrand series, in one group (Lower Cape System); **35**, p. 209. My ideas regarding the stratigraphy of the Transvaal have been considerably modified since the publication of the results I had obtained in 1890 after a residence of a few months in the country.

[1] F. H. Hatch, **26.** An error occurred in the first edition of this map in placing all round the Vredefort boss the outcrop of the Black Reef series between the Dolomite and the Gatsrand beds, whereas it ought to be placed between the Dolomite and the amygdaloidal diabases. This error has been corrected in the new edition recently published.

[2] J. G. Bousquet, **3**, p. 38, and Nicol Brown. The succession of the rocks in the Pilgrim's Rest district. *Trans. of the Geol. Soc. of South Africa*, ii. p. 3. Johannesburg, 1897.

At Kromdraai, to the north of Krugersdorp, where the Black Reef series can be well examined in the mines, an interbedded vein of gold-bearing quartz occurs associated with a bed of clay-slate and lying between two bands of quartzite, as given in the text of figure 5.

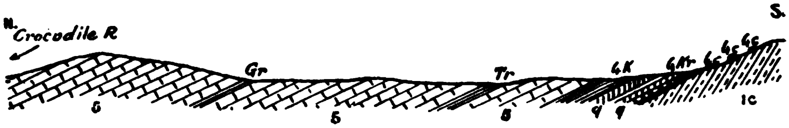

Fig. 5.—Section near the Kromdraai mine (from documents provided by Mr. Dorffel, Consulting Engineer for the Company). Horizontal scale, about 1 : 7500; Vertical scale, 1 : 6000.

5. Dolomite.	*Gr*, Galena Reef; *Tr*, Tweefontein Reef.
4. Black Reef series. Inclination, 15° to 20° towards the north.	4*K*, Clay-slates, called *Kromdraai Slates*, 40 to 52 feet.
	q, Upper quartzite with bands of interstratified clay-slates, 16 to 25 feet.
	4*Kr*, Interbedded vein of auriferous quartz with arsenical pyrites, called *Kromdraai Reef*, 1½ to 3 feet.
	Clay-slate, 1½ feet.
	q, Lower quartzite, 20 feet.
	4*c*, Auriferous sandstones and conglomerates, 3 feet.

1*c*, Schistose conglomerate of the Vaal River System, dip 35° towards W.S.W.

In this vein, which has been successfully worked, the gold is associated with arsenical pyrites and pyrites. These clay-slates, known as the *Kromdraai Slates*, form a constant horizon of great extent.

In the lower part of the Dolomite series, which rests conformably on the Black Reef series, certain clay-slates are found interstratified near the base, which have much analogy with the Kromdraai Slates, whence it follows that the line of demarcation between the Dolomite and the underlying Black Reef series is ill-defined and therefore somewhat arbitrary.

2.—Dolomite series

This series is composed of beds of dolomite and of dark blue or black dolomitic limestone from 4 inches to 10 feet thick, alternating with thin bands of chert. Occasionally, as I have observed near Vereeniging, the chert occurs in nodules arranged in rows parallel to the planes of stratification as in the chalk of

Europe. The bands of chert offer more resistance to denuding agencies and are also less soluble in water than the dolomite, and as a consequence form outstanding ridges, giving a striated appearance to the rocks of this formation as seen at some distance. In the lower part the beds of dolomite are much thicker than in the upper part, where the layers of chert tend to predominate. It therefore results that the lower beds of dolomite are often extremely eroded and hidden by more recent deposits, whereas the upper beds stand out in characteristic escarpments. In those areas where the upper cherty portion of the dolomite series prevails, the soil is so covered by chert débris that only a very careful examination reveals the dolomite as if compressed between the projecting layers of chert. This phenomenon explains how many observers have exaggerated beyond measure the importance of the chert in the dolomite.[1] This difference between the upper and the lower zones is specially evident at the points where the formation has an average inclination, and it can be readily understood that where it occurs highly tilted or practically horizontal these differences more or less disappear.

The degree of inclination of the dolomite strata has a marked influence on its power of resistance to denuding agencies. Wherever its position is horizontal or very slightly inclined, although not a hard rock, and comparatively very soluble, it behaves as a rather resistant element in the landscape, because the layers of chert one after the other offer great resistance to the denuding action of wind and water. The results of the atmospheric agencies are very different when the strata are highly inclined or vertical; the beds of chert then break down as soon as the layers of interbedded dolomite are corroded to a certain depth, and denudation proceeds rapidly. Consequently, wherever its position is horizontal, the dolomite forms an easily recognisable feature in the topography, whereas wherever its beds are highly inclined or vertical it must be sought only in the valleys, where it is often hidden by more or less marshy superficial deposits.

The surface of the dolomite exposed to the atmosphere is wrinkled and furrowed, and the Boers have characteristically named it *Olifants-klip*, because of the resemblance of the weathered surface to the hide of an elephant. The landscape in the country where dolomite prevails greatly resembles that of the Austrian *Karst*. Grottoes, gorges, and sink-holes abound. The grottoes are often partly filled up with stalactitic limestone[1] and with deposits of calcareous tufa or travertine, often containing fossil bones. Sometimes true bone breccias occur in these caverns. A systematic study of these bones, which will doubtless afford interesting results, has not yet been made. Up to the present the remains found there have been exclusively those of a pleistocene and recent fauna.

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[1] W. H. Penning has given the name of *Chalcedolite* to this formation, **50**, p. 576, and **51**, p. 456.

In the dolomite area streams often disappear in the fissured ground and form underground watercourses through a series of irregular caves, in which the river opens out sometimes into subterranean lakes. In this way the Mooi River is lost near Wonderfontein, and below this point the greater part of the water follows an underground course; twenty miles further on it reappears from the dolomite, forming the celebrated spring called *Gerhardminnebron*, the discharge from which is, on account of hidden tributaries, sensibly greater than that of the river where it disappears.

The dolomite is of considerable economic value to the country, because the water from the heavy rains during the wet season from December to March filters rapidly into the rock fractures and caverns, which constitute a network of reservoirs of immense capacity. This reserve of accumulated water reappears at the surface in a large number of strong springs, which scarcely diminish in flow during the dry season. It is to these remarkably constant springs that nearly the whole of the perennial rivers of the western half of the Transvaal owe their existence, such as the Harts, the Malmani, the Malopo rivers, the Schoonspruit, the Mooi, the Klip, the Crocodile, the Aapies, the Pienaar's, Marico rivers, etc.

Regarding the position of the Dolomite series it is generally considered to-day that it is laid down absolutely conformably on the Black Reef series, an opinion confirmed everywhere by mining operations, sometimes in the Black Reef series, sometimes in the lower levels of the dolomitic series (fig. 5 and Pl. II.).

As a rule, the dolomite has a very uniform development, and it is very easy to recognise on the surface. It stretches over a great portion of the Transvaal, and indeed beyond the boundaries of the country; thus it attains an enormous development in the Campbellrand (Griqualand West) and in the Han-Ami-Plateau Namaqualand), where it was recognised by Schenck.

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[1] Many of these grottoes are very beautiful and worth visiting. One discovered in 1897 at Sterkfontein [68], to the north of Krugersdorp, was a splendid natural curiosity; stalactitic draperies adorned the walls, and the stalactites were entirely covered with magnificent needle-shaped crystals of arragonite. The numerous visitors who arrived from Johannesburg destroyed this marvel in a few weeks' time, and as the grotto was on private property the Government unfortunately could not interfere.

ORE DEPOSITS.—Throughout the dolomite formation one finds a considerable number of bedded veins of mineralized quartz, and, towards the base and the top, some bands of interstratified shales. In the central portion of the Transvaal there is found near the base of the dolomite a complex of shales and slates, accompanied by a bedded quartz vein carrying pyrites, manganese, and gold. These slates have been named the *Tweefontein Slates,* and the vein the *Tweefontein Reef.* This auriferous zone is very persistent, and I have found it nearly always where the base of the dolomite crops out. The large quantity of manganese contained in it is very characteristic, and the entire zone is often represented solely by a thick bed of manganiferous and auriferous ground containing irregular veinlets of quartz. This belt has up to the present been very little worked, still one has to place to its account the interesting auriferous deposits of Barrett's Berlin[1] (Pl. II., Sections 2 and 3) and of Spitskop, on the eastern escarpment of the high plateau in the Lydenburg district. The auriferous zone has a greater development here, and its composition is considerably altered by the influence of diabasic intrusions; this diabase being greatly decomposed, forms a kind of laterite, which mingles with the manganiferous débris from the higher and entirely denuded beds of dolomite. The beds of Barrett's Berlin are worked open-cast.

The sandstones of the Black Reef, weathered into fantastic shapes (fig. 6), which underlie these auriferous deposits, outcrop to some extent on the magnificent escarpment of Duivel's Kantoor. On the more or less furrowed surface of the sandstone alluvial deposits of small extent are worked, and during a period extending over more than a dozen years numerous nuggets of gold have been found. The large nugget weighing 52 ounces which was shown at the Universal Exhibition at Paris in 1900, in the pavilion of the South African Republic, comes from this deposit. It was found in 1898 on the main road, and still carries the marks of coach-wheels which bumped over it. The gold from these fields must have been derived from the dolomite, which has now disappeared through erosion, and the bed containing the precious metal represents in a concentrated form its final remains.

From the south of Pretoria to the district of Marico in the west, a second mineralized zone occurs in the lower dolomite, but with frequent gaps. It is a bedded galena lode accompanied by a bed of shales; its position in the dolomite is nearly 200 feet higher than the Tweefontein Reef. Usually, as at Kromdraai, it is a vein with clean-cut walls, and the gangue consists of quartz with a little fluor-spar; there are only found in it lead ores as galena, cerussite, and pyromorphite. But it is not unusual for this vein to expand into a series of pockets; when this occurs the mineralization is more complex, and in these pockets the following minerals are found: galena, blende, smithsonite (zinkspath), calamine (Kieselzinkerz), mimium, pyrites, malachite, cinnabar, talc, calcite, and fluorine.[1] All around these lodes the dolomite is impregnated with numerous crystals of tremolite, or of talc; the latter mineral being here regarded as a product of the decomposition of the tremolite.

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[1] See G. A. F. MOLENGRAAFF, 37, p. 134.

Sphalerite

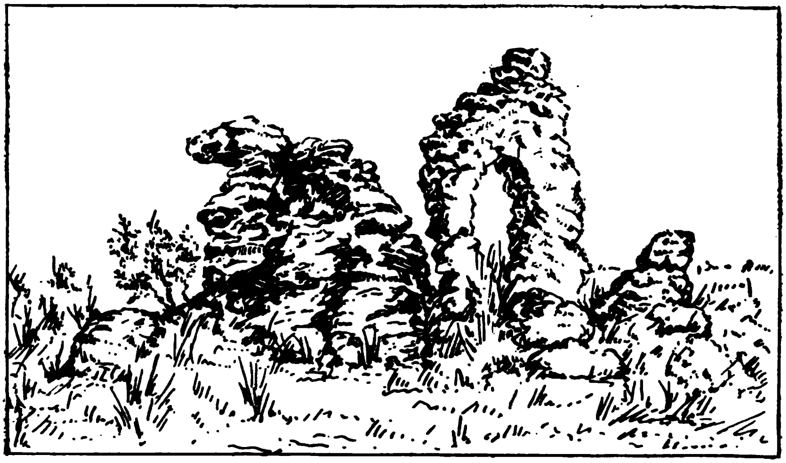

FIG. 6.—Effects of weathering in the Sandstones of the Black Reef series at Duivel's Kantoor.

In the eastern part of the Transvaal (Lydenburg district) mineralized bedded veins, particularly at the base and near the top of the formation, are much more numerous. They are for the most part gold-bearing and are largely worked.[2] Besides gold and quartz these veins carry ores of iron, copper, and manganese.

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[1] In 1893 I described one of these pockets in the dolomite of the Marico district; see **34**, p. 150. I think now that I was in error in representing (p. 152) the dolomite beds as resting unconformably on the shales, which crop out in the neighbourhood with a low inclination to the north. These shales are very probably interstratified conformably with the dolomite.

[2] For the details of the beds, see J. G. BOUSQUET, **3**, p. 37, and A. BORDEAUX, **2**, p. 300 and following.

In the Marico district true quartz reefs are worked. They occur near the source of the Malmani River and constitute the Malmani Goldfields. We have here to do with vertical reefs in the dolomite, having an average strike N.N.E. and S.S.W. The quartz carries much visible gold, and some of the reefs, such as the Mitchell Reef and the Pioneer Reef, have yielded magnificent specimens. Besides gold and decomposed pyrites or limonite, there are found small quantities of copper ores, as malachite, azurite, bornite[1] (erubescite), and copper pyrites. The working of these reefs has not, up to the present, yielded very satisfactory results, because their gold contents are too variable, and to this is added the practical difficulty arising from the presence of enormous volumes of water given off by the enclosing cavernous dolomite.

In the Lydenburg district an upper and a lower group of gold-bearing veins can be distinguished in the dolomite. The lower group comprises veins of the Tweefontein type, which are rich in manganese. The Spitskop and Barrett's Berlin mines, previously alluded to, belong to this group, and this horizon is known to the miners of the district under the name of *Digger's leaders* (Pl. II., Section 3). The majority of the reefs worked in this district form part of the upper group, and are characterized by their cupriferous contents, which are entirely absent in the reefs of the lower group.

In the Lydenburg district the Dolomite series is much more cut up by the diabase dykes than elsewhere; and interstratified intrusive sheets often form the roof or the floor of the auriferous bedded reefs. It seems undeniable that there exists a certain relation between the intrusive rocks and the distribution of gold in this formation.[2]

THICKNESS AND AGE.—The thickness of the Dolomite series in the basin of the Witwatersrand can be estimated at 2600 feet; in the neighbourhood of Pretoria, at 5000 feet; near Godwan, at 1650 feet; in the vicinity of Lydenburg, at 2600 feet; and in the Makapan Mountains, at 4000 feet.

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[1] For the details of these lodes, see G. A. MOLENGRAAFF, **35**, p. 254, and M. FRANCKE, **20**.

[2] J. G. BOUSQUET, **3**, p. 39 and pp. 40 to 44. For the stratigraphy of the Transvaal System see the section of Mr. A. STARK, after Mr. NICOL-BROWN, reproduced in Plate II., Section 3. NICOL-BROWN, *The Succession of the Rocks in the Pilgrim's Rest District*, *Trans. of the Geol. Soc. of South Africa*, ii. p. 1. Johannesburg, 1897.

Up to the present it has been impossible, by direct evidence, to fix the age of the Dolomite series. It is true that COHEN[1] has made mention of some siliceous beds whose corroded surfaces bear the prints of Crinoid stems and of Brachiopods resembling species of the genus *Orthis* and *Chonetes*, which would allow them to be classified as Palæozoic. But these indications are very vague, and have not up to the present been confirmed by further evidence.

As has been previously remarked, the lower limit of the Dolomite series is not well defined, but the uncertainty regarding the upper limits is still more marked. The fact that near the top of the series there are found some beds of clay-slates interstratified with the dolomite, and higher some bands of chert interstratified with flagstones and with clay-slates, which are indistinguishable from those of the Pretoria series, renders more or less arbitrary the level which may be considered the boundary between the Dolomite series and the Pretoria beds, which overlie it conformably. But this difficulty is still further increased by the numerous grottoes and caverns in the dolomite, which have produced such frequent sinkages in the upper part of the dolomite that the beds are very much broken up at the zone of contact between the dolomite and the Pretoria beds, resulting in an irregular undulating surface.

IGNEOUS ROCKS.—Dykes of diabase can be found in many places in the dolomite, but are nevertheless not plentiful. Interstratified intrusive sheets are common in the district of Lydenburg, but seem to be rare elsewhere. Near Ottoshoop an important dyke of rather interesting gabbro with quartz and amphibole[2] intersects the Dolomite series. The handsome rock of Wonderfontein, which is used in Johannesburg as a building-stone, is derived from a nepheline-syenite-porphyry, a kind of foyaite, which also forms an enormous dyke through the dolomite. Since 1900 the occurrence has been ascertained of intrusive sheets or masses of bright-red coloured tonalite of considerable thickness, found in the lower division of the Dolomite series in several localities in the Southern Transvaal, as, for instance, at Zwartkop [476] in the Pretoria district, and at Rietfontein [555] in the Potchefstroom district. Also in the majority of the boreholes, sunk through the dolomite in the East Rand Extension, sheets of tonalite have been struck in the same horizon.

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[1] Communicated by P. H. DAHMS, **13**, p. 118.

[2] For a petrographical description of this rock, see G. A. F. MOLENGRAAFF, **35**, p. 221.

3.—PRETORIA SERIES[1]

The Pretoria beds consist of a series of flagstones, clay-slates, shales, quartzites, and sheets of interstratified diabase. The outcrops of the quartzites, which resist the weathering agencies, form ridges or escarpments on the surface, and can be followed for enormous distances. Each of these quartzite belts, having rather persistent characteristics, constitutes a leading formation of great value for the detail stratigraphy of this series. Let us choose, for example, the country between Pretoria and the Crocodile River, where the Pretoria series is largely developed. This area consists of three ranges of hills with an east and west direction, separated the one from the other by large valleys. The most northern forms the Magaliesberg, an imposing range, rising to 700 feet above the surrounding plains; it can be followed like a gigantic wall for a distance of some hundreds of miles, without its crest varying in altitude (5250 feet above sea-level on an average), or its nearly perpendicular southern escarpment becoming less threatening. The second range is that of Daspoort[2]; the third, near Pretoria, is called Timeball Range. The crests of these ridges are nothing but the outcrops of the quartzite beds, whilst the intervening clay-slates must be sought for in the valleys.

The dip of the Pretoria beds being on an average from 25° to 40° to the north, the slope of all these hills towards the north corresponds with the inclination of the strata, and is consequently slight, while the southern declivity is extremely precipitous.

In descending order there can be distinguished in the series in the vicinity of Pretoria the following beds:—

Sandstone and arenaceous clay-slates to the north of Magaliesberg.
23. Coarse sandstone.
22. Quartzites of Magaliesberg, forming a quartzitic belt about 575 feet thick, divided in two by a bed of arenaceous clay-slates.
The strata 23 and 22 form the crest and the northern slope of the Magaliesberg.
21. Clay-slate.
20. Diabase.
19. Chert on the southern slope of the Magaliesberg.
18. Repeated succession of clay-slates, shales, and interstratified sheets of diabase.
17. Daspoort quartzite. This quartzite forms the crest and the northern slope of the hills in the Daspoort range.

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[1] In 1890 I wrongly considered this series as forming part of the South African Primary System, **35**, p. 205.

[2] On Jeppe's map this range is called Witwatersberg.

16. Coarse-grained intrusive diabase.
15. Flagstones in thick beds, used as building-stone for the foundations of houses in Pretoria. These flagstones are worked near Daspoort, on the right bank of the Aapies River, to the north of Pretoria, and on the south side of Meyntjes-Kop.
14. Clay-slate.
13. Dark violet ferruginous sandstones.
12. Clay-shale and diabase.
11. Amygdaloidal diabase.
10. Clay-shales and numerous sheets of intrusive diabase interbedded alternately. Interbedded also with the lower part of this group are some thin bands of quartzitic rock.
9. White quartzite.
8. Black quartzitic sandstone with magnetite; the cementing magnetite is very rich, and its volume is much greater than that of the quartz particles. This rock is a good iron ore. Beds 9 and 8 form the crest and the northern slope of the hills of the Timeball Range; the black outcrops of magnetite contrast strongly with those of the white quartzite, even at great distances.
7. Quartzite and sandstone with a clearly marked false bedding.
6. Sandstone highly charged with magnetite, the surface of which, weathered by atmospheric agencies, presents strange outlines.
5. Clay-slate.
4. Quartzite.
3. Clay-slate.
2. Flagstones, giving here fine slabs used in Pretoria for pavements of side-walks. The flagstones are worked in large quarries on the south side of the hill on which Fort Klapperkop is situated, and also on Erasmusdam, south of Schanskop.
1. Yellow clay-slate, with one or two beds of chert interbedded here and there; these beds can be regarded as the strata forming the transition from the underlying dolomites.

Chert. The upper bed of the Dolomite series.

The thickness of these beds may be estimated as follows:—

20. Valley to the north of the Magaliesberg Mountains, 330 feet.
19. Magaliesberg Mountains, 1300 feet.
18. Magaliesberg Valley, 3600 feet.
15 to 17. Daspoort Range, 900 feet.
10 to 14. Valley to the west of Pretoria, 2500 feet.
1 to 9. Timeball Range, 1300 feet.

The constitution of the Pretoria beds is fairly constant in the central and eastern part of the country. Some of the characteristic leading beds enumerated above are still recognizable, with almost the same characters, in the Lydenburg district, that is, at a distance of more than 140 miles from Pretoria. Thus, one may regard the thick belt of quartzite through which the railway tunnel has been pierced between Waterval Boven and Waterval

Onder,[1] as the equivalent of the Daspoort quartzite, and the bed of sandstone and quartzite with magnetite crossing the railway at Nooitgedacht,[2] as the equivalent of the magnetite belt of the Timeball Range. These beds of quartzites are very easily distinguished in the topography as they form prominent *kransen* (fig. 7) along the whole eastern escarpment of the high plateau in the Lydenburg district.[3] In the Witwatersrand basin, where the Pretoria beds are represented by a complex, locally known as the *Gatsrand Beds,* their development presents considerable analogy; only, the sandstones and the diabases are more prominently represented there than in the neighbourhood of Pretoria.

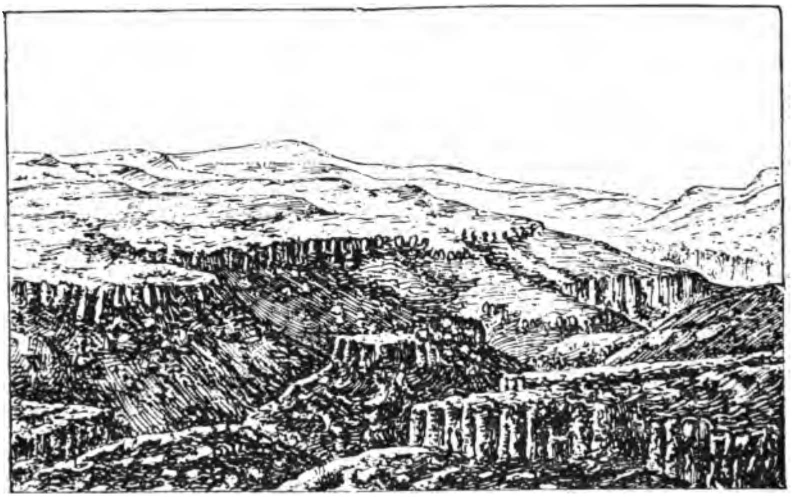

Fig. 7.—The *kransen* in the Pretoria series between Waterval Boven and Waterval Onder.

Marls and limestones have so far been found only in a few localities, interstratified between the clay-slates of the upper portion of the Pretoria series, as for example at Van Lenneps-Kopje, a short distance from the village of Waterval Boven. The search for fossils in these beds has not been successful. It is interesting to note in the clay-slates of the upper part of the series near Belfast, the presence of a bed of slightly argillaceous limestone with a very fine and even grain, which could, as shown by trials made in Johannesburg, be used as a lithographic stone. From its variegated colour it would also make a very fine ornamental stone—a marble for building purposes.

[1] Residence of President Kruger after the capture of Pretoria.
[2] Camp of the British prisoners after the taking of Pretoria.
[3] See **37**, fig. 5.

To the west of the meridian of Pretoria, the character of the Pretoria slates, and particularly that of the clay-slates, begins to change, the latter becoming more and more ferruginous. To the west of Buiskop the Pretoria beds are principally represented by slates which have a strong resemblance to the ferruginous slates of the Hospital Hill series. In the district of Marico the clay-slates of this series are also harder and richer in iron than in the vicinity of Pretoria. Beyond the border, in Griqualand West, the Pretoria beds, resting on the dolomite of the Campbellrand, are very hard and ferruginous, and for a great part consist of jasper,[1] between the thin bands of which are found layers of a rare amphibole, called crocidolite.

Ore deposits.—The results of prospecting work up to the present show that the Pretoria beds are not very rich in ore deposits.

In the lower part gold-bearing beds of quartz are found, bearing a very strong analogy with those found in the dolomite. Working in these reefs has been begun at Koesterfontein [108] and at Blaauwbank [104], to the west of Krugersdorp, but without favourable results. At a slightly higher level must be placed the beds of Scheerpoort [150], some twenty miles to the north of Krugersdorp, the working of which has been tried several times without much success. Better fortune has attended the attempt in the Lydenburg district, where profitable work has been carried on in the bedded vein of auriferous quartz, called Bewitt's Reef, situated near the base of the Pretoria series in the neighbourhood of Frankfort.[2]

In the upper portion of the Pretoria series lodes of copper and lead have been found in the districts of Pretoria, Rustenburg, and Lydenburg. The ores in these lodes contain a certain percentage of silver, hence the workings on them are known as 'silver-mines.'

There exists an evident relation between the occurrence of these lodes and the dislocations connected with the phenomena of intrusion and eruption of the rocks of the plutonic series of the Bushveld; and while analysing the latter, we will study these ore deposits somewhat in detail.

Igneous rocks.—The Pretoria beds are intersected by a great number of diabase dykes and are interstratified with numerous sheets of this rock. One can easily study the contact between these dykes and sheets and the deposits of the Pretoria series in the remarkable railway cutting between Belfast and Godwan. In the whole series I have counted in this section fifty-six sheets of diabase of a thickness of more than ten feet, besides a very large number of less thickness. Some beds of amygdaloidal diabase also occur, which may be contemporaneous with the formation of the series, but the sheets of diabase are intrusive, as clearly evidenced by the clay-slates, both above and below the sheets of diabase, being frequently metamorphosed into hornstones. A strong argument is presented by fig. 8, where a diabase dyke is shown to pass into a sheet. A fine example of contact metamorphism can be seen close to Pretoria at Meyntjeskop, in a thick bed of coarse-grained diabase interbedded between the quartzite of Daspoort above and the clay-slate below. Near the plane of contact the slate is indurated and much less fissile than a little lower, where it is unaltered, whilst the quartzite, also hardened, is, near the plane of contact with the diabase, charged with small crystals of epidote and bundles of actinolite needles (fig. 9).

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[1] G. W. Stow, **60**, p. 581.

[2] J. G. Bousquet, **3**, p. 44.

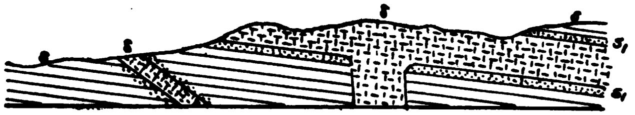

FIG. 8.—Diabase dyke giving rise to an intrusive sheet at kilometre 219 on the railway from Komatipoort to Pretoria. Scale, 1 : 1000.

s, Clay-slate of the Pretoria series; s_1, indurated slate; δ, diabase.

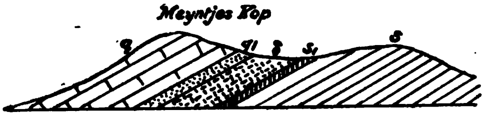

FIG. 9.—Intrusive diabase in the beds of the Pretoria series, near Pretoria.

q, Daspoort quartzite, thickness, 55 feet; q_1, altered quartzite, charged with epidote and actinolite; δ, Gabbro diabase, coarse-grained, thickness, 50 feet; s_1, hardened clay-slate; *s*, clay-slate, thickly bedded, thickness, 115 feet.

The strata of the Transvaal System, which are, as previously remarked, superimposed with evident unconformability on those of the South African Primary System,[1] are not highly tilted as a rule, the angle of dip scarcely ever exceeding in all the

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[1] The sections of Pl. II. give a good idea of the unconformable character of the Transvaal System on the older rocks.

Lydenburg district 7° to 15°. There are, however, numerous exceptions. All around the granitic boss of Vredefort the Transvaal System has been subjected to movements similar to those of the underlying South African Primary System; hence the strata of the Black Reef series, the Dolomite (Pl. II., Section 1), and often those of the Gatsrand series, are vertical there, or even overtilted, but the angle of the tilting gradually diminishes higher up in the Gatsrand beds, which are identical with the Pretoria series.[1] The same facts are observable in the Makapan Mountains (fig. 10); there, the average inclination of the strata of the Transvaal System, which is evidently unconformable on the Archæan rocks, does not exceed 20°, but in some places the beds are tilted vertically. Our knowledge of the geological structure of the Transvaal is only sufficiently advanced at points too far removed from one another, to allow us to explain the more or less local causes of the phenomena of tilting of the Transvaal System. But one can gauge with more accuracy the reason why the inclination of the strata of the Transvaal System is directed towards a common centre in the central part of the Transvaal. In the large tract to the north of Pretoria the dip of the strata of this system is seen to be directed and to go on increasing towards the area known as the *Bushveld*, where, as we shall see later on, intrusions and eruptions of a magma rich in soda have occurred after the formation of the Pretoria beds. The latter are, up to a certain distance from this basin of igneous rocks, tilted, dislocated, and even sometimes bent in large folds.

OUTCROPS.—The lines of outcrop and the dip of the strata of the Pretoria beds and of the Black Reef series indicated on the map (Pl. I.) give an idea of the outline of the country occupied by the lower group of the Transvaal System. To the north of Pretoria the basin of the Bushveld is seen to be surrounded on all sides by a belt representing the lower division of the Transvaal System, interrupted only to the south-east, where it is hidden by the overlying Karroo beds, and to the north, where the large fold which separates the basin of the Bushveld from the basin of the Waterberg is in part hidden by the igneous rocks and the sandstones of the upper division. On the east and west sides of the Waterberg basin the continuation of this belt, formed by the lower division of the Transvaal System, is very little known, as the geology of that district has not been investigated. The beds of the Transvaal System on the southern edge of the Bushveld are also seen to be in open connection with those in the basin, or rather the trough of the Witwatersrand, of which the continuation to the south-east is hidden under the Karroo deposits. The lower portion of the Transvaal System has an enormous development in the Campbellrand in Griqualand West, and in Bechuanaland, but this area is beyond the boundaries of our map.

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[1] G. A. F. MOLENGRAAFF, **44**, p. 22.

4.—PLUTONIC SERIES OF THE BUSHVELD

I have given this name to a group of intrusive and eruptive rocks, having as a common character a high percentage of soda, the intrusion of which took place at a period subsequent to that of the formation of the Pretoria series, and prior to that of the Karroo System.

RED GRANITE.—One of the typical representatives of this group is the red granite, a rock which occupies a vast area to the north of Magaliesberg, in the Bushveld, and which thirty years ago had attracted the attention of the first explorers, Mauch, Hübner, and Cohen. This red granite is a granular rock, composed of red feldspar, generally anorthoclase or orthoclase, of quartz, and of small quantities of strongly pleochroic amphibole or biotite. The small proportion of dark constituents gives this granite as a body a reddish colour, the decomposed superficial parts being grey or white. This granite, though granular, has usually a perfect micropegmatite structure; this type is very persistent, and I have collected specimens impossible to distinguish from one another in localities separated by several hundreds of miles, as at Crocodilepoort [411] and at Honignestkrans [121] to the north of Magaliesberg (district of Pretoria), at Klipfontein [1926] (district of Waterberg), and on the northern slope of Botha'sberg (Middelburg district). In the former geological descriptions of the Transvaal, among others in that of Schenck, the authors do not suspect the difference between this red granite and the old granite, and regard the 'district of the Bushveld as belonging to the South African Primary System. This error created stratigraphical difficulties more and more insurmountable as our knowledge of the geological structure of the country increased. These difficulties are solved the moment we admit that the red granite and the other igneous rocks which accompany it are of a later age than the grey granite of the South African Primary System, that is to say, that their intrusion was subsequent to the period of formation of the Pretoria series.

The geological position of the red granite is clearly shown in Section 1 (Pl. II.). If, starting from the mass of granite lying between Johannesburg and Pretoria, one travels towards the north, it is seen how the old granite is covered by the Black Reef series, and how this formation is succeeded conformably first by the Dolomite and then by the Pretoria series, always with the dip towards the north. Then, overlying the Pretoria beds and to the north of Magaliesberg, one meets the red granite and, at its base, norites and syenitic rocks. If, from the neighbourhood of Lydenburg, we travel towards the west we find exactly the same succession (Pl. II., Sections 2 and 3). There also the Black Reef series (sandstone of the Kantoor and Drakensberg) rests uncomformably on the old granite and on the schists of the Primary System; higher comes the dolomite, and above the dolomite, in the Steenkamp Mountains, lies the Pretoria series, always with a dip towards the west, increasing from 7° to 25°. Finally, in the Botha Mountains and in the country of Secoecoeni, the red granite covers the Pretoria series with syenites and norites at its base, the latter accompanied by beds of magnetite. The same order is found in the mountains of Makapan (fig. 10). At Button's-kop the Black Reef series, with a westerly dip, rests unconformably on the schists in which the Eerstelling gold-mine occurs and on

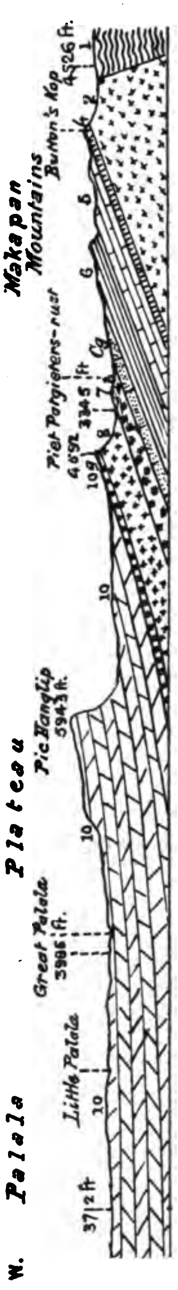

FIG. 10.—Section showing the divisions of the Transvaal System lying uncomformably on the South African Primary System in the North of the Transvaal. Longitudinal scale, 1 : 750,000.

10 Waterberg sandstone; 10g, Conglomerate at the base; 8 Red granite; Cg, Limestone with garnets; 6, Flagstones, sandstones, quartzites, and diabases of the Pretoria series; 5, Dolomites, limestones, and cherts of, the Dolomite series; 4, Quartzites, conglomerates, sandstones, clay-slates and greywackes of the Black Reef series; 2, Old granite; 1, highly tilted schists of the South African Primary System.

the old granite. Above the Black Reef comes the dolomite, overlaid by the Pretoria beds and, at the upper part, near Piet-Potgietersrust, by the red granite, still with the associated norite at the base. This norite gives rise, near the latter village, to fractured hills resembling the hills called Zwartkoppies and Pyramids, on the northern slope of the Magaliesberg.

The following comparative table gives the principal characters of the old granite and the red granite:—

Old Granite.	**Red Granite.**
Colour generally more or less deep grey, very rarely red.[1]	Colour nearly always red.
In the majority of cases granite with biotite or biotite and hornblende, rather frequently also granite with two micas and rarely granite with muscovite.	Generally granite with hornblende and biotite, sometimes granite with hornblende, and rarely granite with biotite. Muscovite has never been found.
Feldspathic element represented largely by microcline and plagioclase	Feldspathic element represented nearly exclusively by anorthoclase and orthoclase.
Micropegmatite structure unknown.	Micropegmatite structure generally admirably developed and characteristic.
Veins of pegmatite very common, giving an intersected appearance to the rock.	Veins of pegmatite not yet met with.
Deep-seated rocks almost exclusively of the granitic order.	Deep-seated rocks of the granitic order, of the syenitic and of the gabbro order, associated with red granite in accordance with a certain law.
Rocks which may be regarded as effusive representatives of the granite, unknown.	Near the region of the red granite there are often found rocks of various types, which may be regarded as effusive or marginal types of the above classes of deep-seated rocks. The typical red granite with micropegmatite structure is itself probably a marginal type (*Randfacies*) of the very coarse-grained red granite without micropegmatite structure which I found in some of the central portions of the Bushveld, as, for instance, in the vicinity of Zoutpan, twenty-four miles north of Pretoria.
One scarcely ever finds, except quite close to the contact with the	Segregation of the more basic elements is most marked both on a

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[1] I have found, somewhat rarely, red varieties of old granite in the Vredefort mass, and also in some localities of the Vryheid district.

surrounding schists, segregations of the more basic elements.	large and a small scale. Thus one finds amphibole in the red granite (which otherwise is rather poor in dark constituents) accumulated in masses of various dimensions, which should be designated amphibolites (*hornblendefels*). The relative distribution and position of the red granites, syenites, norites, and metalliferous deposits in these norites can be attributed to phenomena of segregation (see further on).
Crystalline schists well developed throughout the area of the ancient granite. They often form belts of great length, and in their vicinity the granite has frequently a pseudo-stratified structure, and is altered to gneissose and amphibolite varieties.	Crystalline schists are unknown in the area of the red granite.
Numerous diabase dykes.	Diabase dykes wanting or rather rare.

This table furnishes sufficient evidence of the fact that the old granite and the red granite show such fundamental differences that the one cannot be the equivalent to the other. It is, of course, almost impossible to confound them when one has seen them in the field and observed the character they impart to the landscape.

SYENITES.—Besides the red granite numerous examples occur in the Bushveld of other types of deep-seated rocks not less interesting, such as nepheline (elæolite)-syenite, anorthoclase-syenite, and norite.

The elæolite-syenite, which, for instance, forms a boss of moderate extent on the farms Zeekoegat [287], and Leeuwfontein [320], to the north of the Magaliesberg, is represented by a whole series of varieties, of which those belonging to the foyaite type rank amongst the finest specimens known. The elæolite-syenite of this boss being a foyaite, tends to prove that only the marginal portion of this boss is accessible. Their surface presents a curious appearance; it is pitted with small holes, sometimes hexagonal, sometimes quadratic, casts of the large crystals of nepheline, which, decomposing more readily than the rest of the rock, have completely disappeared. At a slight depth the elæolite is quite unaltered. The large crystals of anorthoclase being flat twins following the Carlsbad law, are much flattened in the direction of the twinning plane, and have a nearly parallel arrangement, giving a sort of cleavage to the whole rock.[1] Similar elæolite-syenites belonging to the foyaite group occur in the Pilands Mountains.

The syenite with anorthoclase, for which Mr. Henderson[2] has proposed the name *Hatherlite*, forms numerous bosses of great extent. I have found them to the north of the Magaliesberg on the farms Waterval [125], Leeuwfontein [320], and Zeekoegat [287], and on the north side of the Bothasberg on the farm Blinkwater [77].

These bosses of syenite present very varied syenitic types, amongst them titanite-syenite and pistacite-syenite, the latter being a rather widespread variety due to alteration by decomposition.

NORITE, GABBRO, AND MAGNETITE.—At the periphery of the red granite area norites and gabbro are nearly everywhere found, their occurrence being generally easily recognized in the landscape by the very accentuated contour of the small hills formed by this rock. They are found to the north of Zeerust, at Alewijnspoort [210] (district of Marico), to the north of Rustenburg, and from there in a nearly uninterrupted zone, forming the Zwartkoppies, along the northern slope of the Magaliesbergen, up to the environs of Pretoria, again on the northern slope of the Bothasbergen (district of Middelburg), and near Piet-Potgietersrust, along the western side of the Makapan Mountains.

They are beautiful rocks, representing, besides gabbro, several varieties of norite, sometimes with enstatite, sometimes with hypersthene, or even with hypersthene and diallage. They have been the subject of a detailed petrographical and chemical study by Mr. Henderson.[3] Pyroxenites, composed solely of enstatite, are often combined with the norite. At Alewijnspoort (district of Marico)[1] the enstatite rocks are granular, with medium-sized grains, while in the small hills called the Pyramids, to the north of Pretoria, they are composed of enstatite crystals of a length which often exceeds four inches. These norites have an economical importance; in fact, lenticular masses of magnetite highly magnetic and very pure are associated with them, forming metalliferous deposits of great extent.

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[1] Hitherto nepheline had only been found in the Transvaal by Cohen in a syenite near Hex River, in the Zwartkoppies range, situated also to the north of the Magaliesberg. This syenite with nepheline has been described by Wülfing, the nepheline being only visible under the microscope. See E. A. WÜLFING, **64**, p. 16.

[2] Mr. HENDERSON has given a very good description of this rock. I too have studied it in microscopic slides, and would be inclined to give it the name *anorthoclase-amphibole-pyroxene-syenite* (*Anorthoklas-amphibol-pyroxen-Syenit*). Henderson prefers to apply distinct names to the different types of anorthoclase rocks, and proposes in this case the name *Hatherlite*, which would be applicable if there were not an error in locality. This rock appears, it is true, not far from the old powder factory on the farm Leeuwfontein [320], but this factory has nothing in common with the 'Eerste Fabrieken' or the Hatherley factory, which is situated on the southern side of the Magaliesbergen, on outcrops of beds of the Pretoria series. See J. A. L. HENDERSON, **29**, pp. 10 to 42.

[3] J. A. L. HENDERSON, **29**, pp. 10 to 42.

These are the best beds of iron ore in the country.[2] It is not difficult to demonstrate that the magnetite is a product of segregation from the norite, because it is everywhere noticeable that the percentage of magnetite, the presence of which as a normal constituent is always proved under the microscope, goes on increasing as one approaches the masses of pure magnetite; finally, all the elements of the norite, except the magnetite, having disappeared, there remains an ore of pure magnetite. It is certain that in the future, as soon as the iron industry has been developed in the country, these deposits will attain considerable importance.

I have found deposits of chromite associated with norite in some localities, for example, on the farm Zilikatsnek [379], to the north of Magaliesberg. These deposits have been very little studied, and no information can as yet be given regarding their extent or value.

As to the relations existing between the principal types of these rocks, it may be stated that the red granite occupies the centre of this vast plutonic area, whilst the other types are confined to the peripheral region. Norite must be sought for in the extreme periphery, and a belt of syenitic rocks, which, however, is not developed so regularly and so uniformly as the norite, separates it from the granite. In accordance with these facts, therefore, we find in this immense plutonic mass a succession of rocks with increasing basicity as one proceeds from the centre to the periphery.

Besides deep-seated intrusive rocks this region is very rich in eruptive rocks of very varying characters. In one part of the red granite region, that is, in the Waterberg district, porphyritic types are found associated with the red granite. Sometimes there occur, as at Magalakwiens-oog, felsitic porphyries with globular quartz, and more frequently felsophyres. The porphyries, with pinitoid, of this district are very characteristic; they are felsophyres in which the phenocrysts of feldspar are entirely altered into pinitoid, the whole forming a beautiful reddish rock with green spots.[1]

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[1] We are indebted to Mr. Henderson, 29, pp. 38 to 41, for a petrographical description and an analysis of this fine rock.

[2] This iron ore has, however, a rather large percentage of titanic acid.

Much more important and varied are the eruptive rocks found near the boundaries of the Bushveld. Sometimes they are porphyries, which might be regarded as the dyke and effusive facies of the syenites and the norites, as, for example, the porphyritic type of anorthoclase-syenite from the Pilandsbergen (Rustenburg district), described by Mr. Henderson[2] under the name of *Pilandite.* But usually the relations are more complex.

Let us cite as proof what is found in the section along the Pienaar's River on the northern side of the Magaliesberg.

On the farm Baviaanskloof the upper quartzites of the Magaliesberg are intersected by numerous dykes of various composition, and further north, on the farm Zeekoegat [287], the same strata are covered, apparently conformably, by stratified igneous deposits, eruptive breccias and conglomerates, silicified tufas, beds of scoriæ altered to breccias of amygdaloidal rocks, all these types alternating with rather thick beds of extremely varied porphyritic rocks, sometimes acid types resembling rhyolites and felsophyres, sometimes basic types such as camptonites, all representing dykes and ancient flows of effusive rocks.

The intrusion and the eruption of the rocks of this igneous series must have been accompanied by gaseous emanations. In the red granite the effluent gases were charged with fluoric comcompounds. In fact, fluor-spar is regularly associated with the igneous rocks of the red granite group, and is one of the most constant minerals in the cavities of these rocks. But it also results from this that the majority of the veins which intersect the red granite are deposits of emanation. In the Waterberg district, for example, the body of quartziferous porphyries and of felsophyres is cut up by numerous veins. The gangue is brecciated and consists of fragments of the walls, on the sides of which the crystals of quartz have crystallized in clusters. The remainder of the cavity is filled with hæmatite alone, or with hæmatite and fluor-spar. In some localities, as at Welgevonden, the veins are more important; it is observed there that the part of the lode next the roof is composed entirely of quartz, while the part next the floor consists of hæmatite, fluor-spar, and quartz. The thickness of the hæmatite with fluor-spar varies from 3 to 10 feet. The hæmatite is very pure and the accompanying quartz is gold-bearing. The working of it has been tried, but the proportion of gold is too variable to admit of satisfactory results.

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[1] Rocks of similar appearance but different composition occur on the farm Roodeplaat [314], in the district of Pretoria. They are Liebenerite-porphyries, in which the phenocrysts of nepheline are altered into pale green Liebenerite.

[2] J. A. L. Henderson, **29**, p. 46.

The same gangue of quartz and specular iron has been found in the Albert silver-mine, situated in the red granite, 45 miles E.N.E. of Pretoria. The chief ore in this working is an argentiferous bornite.

Further, in the other veins of the plutonic series of the Bushveld, the influence of gaseous emanations is disclosed by the fact that the rocks in contact with the veins are deeply impregnated with metallic compounds. This phenomenon is observed, for example, in the veins met with on the north side of Bothasberg, on the farms Rhenosterhoek [110] and Laatste-drift [82]. These lodes intersect the anorthoclase-syenite and the norite and contain sulphide ores of iron, copper, and even, in the latter locality, of cobalt. A deep impregnation of the red granite walls has been proved adjoining the auriferous lode of the Albert silver-mine mentioned above. The ore deposits of the Bushveld are of course still little known and have not been studied methodically.[1]

This plutonic series deserves, apart from the local geology, closer attention, because it increases our knowledge regarding the influence of the intrusive and eruptive masses on the structure of the strata through which they have forced a passage. In fact, these rocks afford striking examples of phenomena an explanation of which modern opinions are still at variance, although known to materially differ from those of former days.

At the beginning of this century the majority of geologists, following Leopold von Buch and Elie de Beaumont, thought that mountain ranges resulted from upheavals produced by the ascent of the igneous rocks which are generally met with within their central axis, as for example in the Alps, where they form the culminating peaks. According to this theory the plutonic rocks were, by their intrusion, the direct cause of the tilting and the disturbing of the sedimentary beds which rest on the crystalline core.

Later, when the study of volcanic regions had shown that the strata through which the eruptive rocks forced their way to the earth's surface were found to be scarcely dislocated, and, after the structure of the mountain chains had been studied more closely, the evidence obtained led more and more to the conviction that the igneous rocks played a really passive rôle in the process of mountain-building. It was at this period that the discovery of the laccolites in the Henry Mountains was published. It cannot be denied that the elevation of the strata forming the sedimentary covering of these was really directly due to the intrusion of the trachytic masses. Later, it was shown that the subsidence and plunging of pre-existing strata into an intrusive magma can produce considerable structural disturbances, phenomena described in a masterly way in the classic work of Professor A. Brögger on the plutonic phenomena in the Christiana basin Just at the time that these ideas were developing, the part played by the intrusive rocks on the one hand, and by the eruptive rocks on the other, was better defined. It was then admitted that the influence of rocks clearly eruptive on the position of the surrounding strata was almost *nil*, whilst that of the intrusive rocks was, on the contrary, generally considerable.

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[1] I have only been able to visit some of the deposits referred to here, and I owe the greater part of the above information to Mr. Dorffel, engineer to Henderson's Transvaal Estates, Limited, a company owning all the deposits of cobalt discovered up to the present in the Transvaal.

The study of the intrusions of the Bushveld, in the Transvaal, shows that the position of the surrounding stratified rocks is considerably modified, and that these disturbances may be regarded chiefly as the consequence of the intrusion of an enormous body of igneous magma.

The changes resulting in the beds of the Transvaal System by the intrusion of the plutonic series of the Bushveld can be summarised as follows:—

(*a*) In the first place, the rocks of the Transvaal System, and more especially those of the Pretoria series, whose zone of contact with the intrusive rocks is nearly the only accessible one, are altered to great distances by contact metamorphism. It is true that in the quartzites of the Magaliesberg this metamorphism is little, if at all, apparent, but in the underlying clay-slates the effect is very marked. The latter are very often altered into *knotenschiefer* charged with andalusite or chiastolite. The schists with chiastolite from the vicinity of Zeerust (district of Marico) are well known,[1] but the schists of Kromdraai [422] (district of Middelburg) are still finer; they are nodular micaceous clay-slates charged with staurolite and andalusite. The staurolite occurs as clearly defined cruciform twin crystals of the St. Andrew's cross type, and the andalusite is developed in pink and pellucid prisms, 5 to 8 centimetres long. Fragments, sometimes of large dimensions, of beds of the Pretoria series are often met, entirely enveloped by the intrusive rocks; in these instances, as they occur to the north of Magaliesberg and to the east of the Pienaar River, the metamorphism of contact is very intense, and even the quartzites themselves are very highly altered, indurated, and epidotized.

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[1] For their description, see **35**, p. 202.

(*b*) Further, numerous dykes intersect the strata of the Transvaal System all around the intrusive mass of the Bushveld; their composition is very varied, but the study of them has scarcely begun. They often extend into the Transvaal System to great distances. Thus, the famous dyke of Wonderfontein [40] in the Krugersdorp district, mentioned first by Hübner, is composed of a magnificent variety of syenite-porphyry with nepheline, a kind of foyaite, which intersects the dolomite and is quarried for building purposes. Frequently these dykes are largely charged with fragments derived from the strata of the Transvaal System. These fragments are highly metamorphosed, and are sometimes so numerous that a true eruptive breccia results in which the igneous rock plays the minor part of a cement. A very fine example of these igneous breccias is that of Derde-Poort [469], five miles north-east of Pretoria. It is a huge dyke crossing the Magaliesberg range; it encloses numerous and often very large fragments of recrystallized dolomite sometimes charged with grossular and other rocks of the Pretoria series equally highly metamorphosed. The igneous cement of this rock is characterized by large flakes of biotite.

(*c*) The dislocations which were produced in the strata of the Transvaal System during the period of plutonic activity are most instructive. The strata of this system, at a certain period, sank under the weight of the intrusive masses, and it resulted from this subsidence that all around the plutonic basin the strata of the Transvaal System dip towards a common centre. In fact, the dip, easily observable, especially in the Pretoria beds, is everywhere directed towards the Bushveld (see Map, Pl. I.).

The most simple case is represented in Section 1, on Pl. II. The whole of the lower Transvaal System is seen there, in the environs of Pretoria, to have subsided and to be bent under the plutonic series, while maintaining uninterruptedly the normal succession of its strata. This simplicity is maintained from

Pretoria towards the west as far as the neighbourhood of Rustenburg, and the section represents exactly what one can observe on going due north from Pretoria by Wonderboompoort. But to the east of Wonderboompoort these simple relations do not continue much further, and beyond the valley of the Pienaar River a character of subsidence different from the preceding may be observed (fig. 11). A series of parallel fractures, step faults (*Staffelbrüche*), has been formed in the sunken portion of the Transvaal System, and as a result one finds a series of small hills consisting of the strata of the Transvaal System all following a common direction, parallel to the periphery of the plutonic area and separated the one from the other by valleys in which can be found the outcrops of igneous rocks belonging to the Bushveld series. The escarpment of all these hills faces south, while their northern slopes are but feebly inclined.

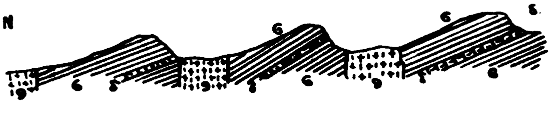

FIG. 11.—Theoretical Section showing the mode of subsidence in the Pretoria series towards the Bushveld and the step faults (*Staffelbrüche*). In the planes of faulting various eruptive rocks are injected, all belonging to the plutonic series of the Bushveld.

9, Eruptive rocks of the Bushveld plutonic series; 6, Magaliesburg quartzites and sandstones; δ, Sheets of diabase.

METALLIFEROUS DEPOSITS.—It is not surprising that a region so disturbed by subterranean forces should be very rich in dykes and in metalliferous veins. In truth, I believe that all the metalliferous veins met with in the different parallel zones and having a general east and west bearing, whether in the beds of the Pretoria series or in the rocks belonging to the plutonic series of the Bushveld, to the east of the Pienaar River (Pretoria and Middelburg districts), have a more or less direct relation with the dislocations of which I have just spoken.

These metalliferous deposits are arranged in the following nearly parallel zones, running mainly east and west:—

(*a*) The zone of the Willows silver-mine, of the mines of Boschkop [295], of Oudezwaanskraal [537], and of the Transvaal silver-mine, all occurring in the same geological horizon, that is to say, in the clay-slates, between the Daspoort quartzite and the Magaliesberg quartzites. They are true fissure-veins and nearly vertical. The fissures are most frequently, as can be best seen in the Willows mine, partially filled with diabase forming a dyke, while the remaining portion forms the lode. The gangue common to all these veins is a siderite (chalybite) carrying a rather high percentage of magnesia and manganese. This carbonate is, when fresh, of a very light brown colour, and passes rapidly by atmosperic action to deep brown and later to a blackish brown. The ore consists of copper pyrites, iron pyrites, tetrahedrite or fahlore (fahlerz), azurite,[1] and malachite; to this complex ore there is added, in the Oudezwaanskraal vein, arsenopyrite, and in the vein of the Transvaal silver-mine, galena, cerussite, and crocoite. The ores of these veins carrying silver are known as silver ores. The silver is associated chiefly with the tetrahedrite. These mines were actively worked ten years ago but are now abandoned, and it is impossible to study the deposits in detail at present.

(β) The zone of lead-bearing lodes occurring in the upper level of the Magaliesberg quartzites. The fissures are filled partly with lead ore; they contain chiefly galena with certain quantities of quartz, calcite, pyromorphite, cerussite, and, in very small quantities, blende and calamine. As a type in this zone may be cited the lead lode situated on the farm Edendale [458], east of Pretoria. In this zone similar lodes in the Rustenburg district have been described to me, but I have not visited them myself.

(γ) The zone of the Balmoral cobalt veins. These occur in the same geological level as the preceding zone, that is to say, in the upper part of the Magaliesberg beds, and it is probable that these two zones are identical, and that the same series of fissures contains lead ore in the neighbourhood of Pretoria and cobalt ore more to the east.

The gangue of these lodes is a kind of hornstone largely impregnated with crystals of actinolite and of smaltine, of which all the small fractures are covered with well-defined crystals of erythrite.

(δ) The zone of veins occurring in the norite at the base of the plutonic series of the Bushveld. On the farm Laatste-drift [82] in the Middelburg district, iron pyrites, chalcopyrite, and smaltine are found in these veins. They are rich in gold, assaying from eight to ten ounces to the ton. At Rhenosterhoek [110], district of Middelburg, a similar vein is entirely filled with very pure massive pyrites. The norite encasing these lodes is completely impregnated with sulphides.

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[1] The azurite of the Willows mine is well crystallized, and its highly modified crystals are very fine. See G. A. F. Molengraaff, **34**, p. 165. The crystals of cerussite which were described in this paper as coming from the Willows mine, were actually found in the Transvaal silver-mine, as subsequently proved by me.

(ε) The zone of copper-bearing lodes in the red granite to which the Albert silver-mine belongs, fifty miles east-north-east of Pretoria. The vein is vertical, with an east and west direction. Both the walls consist of porphyritic anorthoclase granite. The gangue is composed of quartz and hæmatite. The principal ore is an argentiferous bornite, which is accompanied by chalcopyrite, cuprite, chalcosite, azurite, and malachite. The fissure is partly filled with diabase.

The percentage of silver in the bornite of this mine reaches forty ounces to the ton. Similar and parallel lodes have been found in the vicinity; that on the property Roodepoort [359] deserves mention. The gangue of this vein is a siderite, with a large proportion of magnesia and manganese, identical with that of the Willows mine zone, a fact which clearly indicates the relationship of these zones of metalliferous veins. Analogous deposits are not rare in the Rustenburg district.

The rich cobalt deposit of the property Kruisrivier [85], in the Middelburg district,[1] appears to be situated in the zone of the upper Magaliesberg quartzites. The ore is smaltine, carrying from three to four ounces of gold to the ton. This outcrop of an isolated block of strata[2] belonging to the Transvaal System, surrounded on all sides by the plutonic series of the Bushveld, may probably be explained by dislocations of the same order as those described above (see p. 52).

Since it has been shown that there seems to exist a relationship between the movements of subsidence in the Transvaal System and the formation of the Bushveld plutonic basin, it is not less interesting to note that, under the influence of these movements, tensions have been set up, which have induced dislocations of a very complicated character, foldings, and oblique faults of large displacement. In this manner the great fold of the beds of the Transvaal System has been formed, which separates, following an approximate west-south-west and east-north-east direction, the Bushveld plutonic basin from that of the Waterberg. This fold forms the prolongation to the south-west of the Makapan and

[1] H. OEHMICHEN, **47**, p. 271.

[2] This fragment is too small to be indicated on a map of the scale shown in Pl. I.

Chunie Mountains, and then disappears beneath more recent deposits. It is probably the prolongation of this same fold which outcrops afresh in the hills situated a little to the west of Buiskop, in the south-west angle of the Waterberg district. But it is well to remark that the dolomitic limestone and the quartzites and superimposed sandstones that are found in these hills and which should be the representatives of the Dolomite and the Pretoria series, differ considerably, as we have previously remarked, from the normal types of these rocks. In fact, I found on Zwartkloof [2126], west of the Warm Bath, the lowest portion of the Pretoria series represented by ferruginous slates showing a remarkable and sometimes even a deceptive similarity to some types of the Hospital Hill slates. It is clear, if this interpretation be correct, that the continuation of the Transvaal System on the two flanks of this fold must be found underneath the red granite and other igneous rocks of the plutonic series of the Bushveld.

All these phenomena of tension show themselves in a very remarkable manner whenever the periphery of the plutonic basin forms a re-entering angle, as happens near Franspoort, twelve miles east-north-east of Pretoria. The Magaliesberg range, the direction of which was east and west to the north of Pretoria, is seen there to bend back sharply to the south-east. Similarly the two other ranges of hills of the Pretoria series, the Daspoort range and the Timeball range, bend in a direction parallel to the first. The dip of the strata continues in every instance towards the red granite, consequently it alters, in harmony with the changes of direction of the ranges of hills, from north to north-east. These complex movements have given rise to tensions which, in the outer range of the curve, the Magaliesberg range, necessitated an extension in length; consequently the Magaliesberg range was fractured, and the rents so caused have originated the natural gorges called by the Boers *poorten*,[1] and which have been followed by the rivers and the pioneer roads. Generally these crevices are filled with eruptive matter, and one would naturally look there for many interesting dykes radiating from the plutonic area of the Bushveld. Among others the beautiful breccia of Derde-Poort is injected into the gap which intersects the Magaliesberg range at Derde-Poort. In the two inner ranges of the curve the tensions have had an opposite effect, as shown by the strong pressures exerted in a direction slightly oblique to the strike of the strata, of which the result has been the production of very oblique faults with large displacements. I have been able to ascertain[1] that the picturesque grouping of the hills in the neighbourhood of Pretoria, as well as the origin of the magnificent sources of the Aapies River, are due to these dislocations.

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[1] *Poort* is a Dutch word signifying gate, and is very well chosen; it is found with the same meaning in the '*porta Wesphalica*' of the Weser in the Iron Gates of the Danube.

By analogy it may with good reason be supposed that in the different areas where the Transvaal System is found developed, interesting relations will occur wherever the periphery of the plutonic area forms a very convex curve, forcing the line of outcrop of the Transvaal System to curve in the same direction, as to the north of Lydenburg, near the Oliphants River, where the strike of the Transvaal System, which at Lydenburg is north and south, is seen to bend sharply at a right angle, becoming in the mountains of Chunie east and west, and even west-south-west and east-north-east. Geological documents relating to this district are unfortunately wanting.

AMYGDALOIDAL ROCKS OF THE BUSHVELD.—The red granite and the associated rocks are covered, in one portion of the Bushveld, the *Springbokvlakte*, by an enormous sheet of a basic amygdaloidal rock, the cavities of which are filled with transparent calcite, numerous zeolites, especially scolecite and heulandite, agate and opal, the last often in the transparent form called hyalite. Generally this amygdaloidal rock is hidden from view by superficial deposits, consisting of calcareous tufa, in turn usually capped by a clay or mud highly charged with organic matter, to which the local name of 'turf' or peat has been given. Excavations made for working the calcareous tufa for the purpose of supplying a cement factory near Pretoria, as well as the cuttings along the railway from Pretoria to Nylstroom, have proved that everywhere in the Springbokvlakte this amydaloidal rock, to which I have given the name of *Bushveld Amygdaloid*, is found beneath these superficial deposits. This flow, to which the Springbokvlakte owes its absolutely flat[2] surface, embraces approximately an area of 1310 square miles (3400 square kilometres). The eruption of the Bushveld amygdaloid must have been subsequent to the intrusion of the red granite, and it would not be venturing too far to regard this outpouring as the closing stage of the period of plutonic activity in the Bushveld.

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[1] A detailed topographical and geological study of the dislocated ground around Pretoria was in preparation before the war, but the collections in Pretoria and the data necessary for its completion are now in other hands.

[2] The Springbokvlakte is the only true plain in the Transvaal. The monotonous plains of the Upper Karroo present in comparison with it an undulating appearance. It is situated about 3300 feet above the level of the sea.

HISTORY OF THE INTRUSIONS.—In the actual state of our knowledge, derived from facts gathered at points in this area very far apart, the chronological order of the eruptive phenomena in the Bushveld can only be guessed at. It would appear that this activity began by an intrusion of a magma rich in soda in the beds of the Transvaal System, at that time more or less horizontal. In this body, which might be of the nature of a laccolite, the distribution of the magma was such that towards the periphery it became more and more basic, while towards the central and higher part this magma was acid and granitic. Later, the sedimentary roof of the intrusive mass was destroyed, while the strata of the Transvaal System sank on all sides underneath the igneous magma. These strata were consequently curved, fractured, and folded, and the crevices and faults were filled with igneous material found to-day in the form of dykes intersecting the beds of the Transvaal System. At the same time the ascending rocks forced a passage here and there towards the earth's surface, and beds of volcanic débris alternating with flows of lava were formed. It is very probable that the volcanic activity subsequent to these subsidences still continued for a certain time, and that to this latter period is due the enormous sheet of the amygdaloidal rocks of the Bushveld.

It seems to me probable that the salt-pan situated about twenty-five miles north-north-west of Pretoria, on the farm Zoutpan [467], which has an almost perfect crater-like shape,[1] may represent one of the centres of eruptive activity during this latter period. The position of this singular deep crater-like hollow, entirely in coarse-grained red granite, most assuredly of intrusive origin, forces us to conclude that the eruptive products thrown out of this centre and deposited around it have been entirely removed by denudation.

The limits of the area occupied by the plutonic series have not yet been entirely traced. To the south-east (see Map, Pl. I.), in the Middelburg district, it is covered by the Waterberg sandstone and the Karroo deposits, and, in the Waterberg district, by the Waterberg sandstone; but the northern portion of the plutonic basin of the Waterberg is entirely unexplored. It may be estimated that the plutonic series of the Bushveld occupies a total area of more than 23,000 square miles. Of this enormous extent scarcely twenty square miles have been examined. What petrographical discoveries remain to be made in future explorations!

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[1] See description and figures given by Mr. E. COHEN, 10.

5.—SANDSTONE OF THE WATERBERG

In the Waterberg district a sandstone formation occurs resting on the red granite, on the quartz porphyry, and the felsophyre of the Waterberg. In general this sandstone assumes a horizontal position, but, wherever the red granite or the underlying porphyry forms domes, the lower strata of the sandstone may be seen lying against these elevations in a more or less curved position (Pl. II., Section 1, and fig. 10). This same formation is found again on the red granite, or at least associated with the eruptive rocks of this series in the districts of Middelburg and Pretoria, but is much less developed than in the Waterberg district.

The Waterberg sandstone series is formed almost exclusively of sandstone and partly of breccias and conglomerates. Slates play a very small part there. At the base of the series some beds of conglomerate are generally found, having a strikingly spotted red colour. This basal conglomerate is composed of cemented pebbles of various rocks, often very slightly rounded. One finds among the pebbles red jasper, schistose quartzite with magnetite,[1] schistose quartzite with muscovite, white quartzite, quartz, and chert; all these rocks being derived from the Barberton series of the South African Primary System. It is to the numerous fragments of red jasper that these beds of conglomerate in the first place owe their spotted red appearance. The cement is arenaceous or quartzitic, and generally contains a little hæmatite, pyrites, and very rare traces of gold. Besides this basal conglomerate, pebbles are found distributed in small quantities throughout the whole mass of the sandstone. The colour of this sandstone is red, but varies from reddish white to deep red. The red sandstone of Buiskop gives the best building-stone known in the country. False bedding is very common in this formation.

Dykes of eruptive rocks are rare in the Waterberg sandstone at least on the Palala plateau, where I only encountered some dykes of diabase and in several localities dykes of felsophyre. Veins of quartz containing flakes of hæmatite, much resembling the veins found in the underlying quartz porphyry and felsophyre rocks, are not rare in this sandstone.[2]

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[1] The red jasper and the quartzite with magnetite are both representatives of the Hospital Hill slates. See page 7.

[2] Mr. G. G. HOLMES, in *Some Notes on the Geology of the Northern Transvaal*, communicated in May 1904 to the Geological Society of South Africa, remarks: '*Dykes are so thickly distributed over the country that it is impossible to travel more than a mile or so in any direction without encountering igneous rock.*

The Waterberg sandstone occupies a vast area in the Waterberg district, and forms the central plateau of this district, called the Palala plateau. This plateau ends to the north, south, and east in escarpments. That to the south, known under the name of Zandriviersberg, is sixty-five miles long. The average altitude of the Palala plateau is 4600 feet, and one of the culminating points, Hanglip Peak, reaches the height of 5900 feet.

The average thickness of the Waterberg sandstone series can be estimated, in the Palala plateau, at 3300 feet.

Outside this plateau, the Waterberg sandstone occurs in more or less isolated patches, all of which have the stereotyped table shape of mountains formed of horizontal strata, as in the Kranskop near Nylstroom, in the Badsbergen to the south of the Waterberg district, in the flat-topped hills near Elandsrivier, and in several localities of the Middelburg district.[1]

I have found on the Palala plateau, in a greywacke, occurring very high in this sandstone series, impressions of stems of undeterminable crinoids; but there have not yet been discovered any determinable fossils in this formation.

In seeking to determine the position of this series in relation to the other formations of the Transvaal one encounters great difficulties.

It is quite certain that, up to the present, this sandstone series has been found in the Waterberg district always resting on rocks of the Bushveld plutonic series. But, if the deduction be drawn from this that the sandstone series is more recent than the underlying plutonic series, one comes face to face with great difficulties, as when it is sought to explain how the dykes of felsophyre, which intersect the Waterberg sandstone here and there, could have so great an analogy with the felsophyre on which this sandstone rests that these two rocks seem identical even after the most minute examination. Another difficulty arises from the conglomerate at the base. On the banks of the Pienaar River, in the Pretoria district, there occur beds of conglomerate which bear a very close resemblance to the conglomerates at the base of

This is especially the case in the Waterberg, and in other parts covered by the Waterberg beds. The intrusion of these dykes through the stratified rocks in most cases is accompanied by very little disturbance of the latter, but where there is any alteration, the formation appears to dip towards rather than from them.'

[1] In E. J. Dunn's geological map of South Africa, 18, these sandstones in the district of Waterberg and the district of Middelburg have been very properly correlated, and differentiated from the older sandstones and quartzites of Lydenburg, as well as from the newer Karroo sandstones.

the sandstone series in the Waterberg district, and seem to be interstratified or at least associated with more or less stratified igneous rocks of the plutonic series. Nevertheless these very igneous rocks are seen as dykes traversing the conglomerate beds. This apparent contradiction can only be explained by assuming that the beds of conglomerate were in reality pre-existent to and were engulfed and partly traversed by these igneous rocks.

One could offer a more or less feasible explanation of all these phenomena by assuming that the Waterberg sandstone series was originally one division of the Transvaal System laid down conformably on the Pretoria series, and that later the rocks of the Bushveld plutonic series were intruded in the form of a laccolite between these two groups of strata, the Pretoria series forming the floor, and the Waterberg sandstone series forming the roof of the laccolite.

But we think that it is better to await fresh investigations for the solution of this question. We will assume provisionally that the Waterberg sandstone series is the uppermost division of the Transvaal System while postponing till further research furnishes data for determining more exactly their position with regard to the sequence and relations of the successive geological formations of the Transvaal.[1]

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[1] Since this paper was written I have learnt from quite reliable authority that the Waterberg sandstone in the Zoutpansbergen lies horizontally and quite unconformably on the old granite. This is scarcely comprehensible if we take the Waterberg sandstone to be the uppermost division of the Transvaal System, and again proves that the question of the true position of the Waterberg sandstone is still unknown. First of all, it is not certain that all the formations at present regarded as belonging to the Waterberg sandstone series really belong to the same formation. Further, its relation to other formations is in many respects obscure; hence it follows that both the laccolite theory suggested in the foregoing pages and the question whether the Waterberg sandstone must be regarded as a subdivision of the Transvaal System are doubtful, and require fresh geological investigations to be fully settled. (See also the Appendix to this paper, page 89.)

IV.—KARROO SYSTEM

The Karroo System in the Transvaal lies unconformably on the foregoing older formations, and generally occurs in a normal horizontal position. There must be distinguished two principal subdivisions in this system, the *Lower Karroo* and the *Upper Karroo.*

1.—Lower Karroo

As a rule, the strata of the Lower Karroo are horizontal, although they respond more or less to the undulations of the ground on which they are deposited.

In the whole of Southern Africa geologists have accepted the subdivision of the Lower Karroo into two stages, the *Dwyka Conglomerate* and the *Ecca Beds.*

The Dwyka conglomerate is characterized by the presence throughout its mass of numerous blocks and pebbles of various origin, ranging in size from huge blocks some tons in weight to mere grains, imbedded without conspicuous order in a very fine-grained grey or dark blue cement of heterogeneous nature, which weathers into a buff-coloured tough clay. The distribution and the position of the boulders in the clay are quite independent of their size and shape. The boulders generally have their edges rounded, but they are not spherical or elliptical like beach or river shingle, and they are very often covered on one or on several sides by one or more systems of parallel straight striæ. Often the striated sides are more or less flat and polished. They are striated boulders.

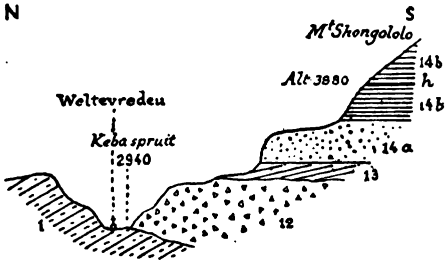

FIG. 12.—Section showing the unconformability of the Karroo System with the Archæan System in the Vryheid district. Scale, 1 : 15,000.

14, High Veld series: 14*b*, Upper Sandstone, 14*a*, Lower Sandstone; 13, Ecca Beds; 12, Dwyka Conglomerate; 1, Barberton Beds and crystalline schists; *h*, Coal horizon.

This short description holds good for the bulk of the formation, which is deposited in thick banks. Within these banks the rock itself proves to be perfectly unstratified, and in places their thickness is such that cliffs some sixty feet in height may be found without sign of stratification. In addition, however, and alternating with this unstratified conglomerate, stratified deposits occur containing in some places pebbles in great abundance, whilst in others the pebbles are rare or entirely absent.

The Ecca beds are usually composed of a very fine indurated mud, without pebbles; large blocks are very rarely found in it. The typical *Ecca-shale* is a kind of very fine-grained clay-shale, crumbling into small pieces through a kind of pseudo-spheroidal or concretionary structure, so that it is hardly possible to obtain from this shale a piece with a few square inches of surface free from cracks. Alternating, however, with these typical friable black shales there occur here and there well-stratified flagstones which yield a good building-stone. All the characteristics of the Ecca beds recur in the stratified portions of the Dwyka conglomerate, and from a petrographical point of view we might therefore speak of an interstratification of true Ecca beds with the Dwyka conglomerate.

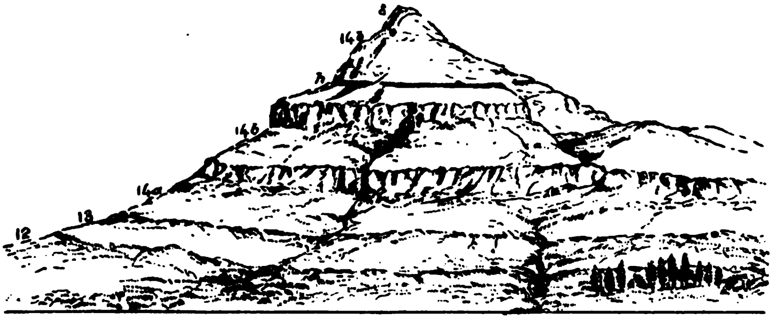

FIG. 13.—Gotshe Mountain and the farm Mooiklip, seen from the south. Same notes as fig. 12. δ, Diabase.

The Dwyka conglomerate has more than a local importance; it has attracted the attention of all the explorers who have interested themselves in the geology of South Africa.

Bain,[1] Wyley, and, later, Moulle[2] regarded it as being of volcanic origin, and respectively gave it the names *claystone-porphyry*, *trap-conglomerate*, and *brèche-mélaphyrique*.

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[1] A. GEDDES-BAIN, 1.

[2] M. A. MOULLE, 46.

Sutherland,[1] in 1868, was the first to propound the theory of the glacial origin of this remarkable conglomerate. He considered it a vast moraine deposit of Permian age. This theory was very favourably entertained by geologists who had been engaged in the study of the rocks of India and Australia, but for South Africa it was not unanimously accepted. Griesbach,[2] Stow,[3] and Schenck[4] advocated Sutherland's theory and gave it strong support. Dunn,[5] although accepting ice action, did not consider the Dwyka conglomerate to be a moraine, but a glacial drift, carried and deposited *in situ* by floating ice.

Green[6] rejected the glacial theory, and regarded the Dwyka conglomerate as a littoral deposit formed along a receding coast-line during a period of gradual subsidence. Draper, Hatch,[7] Sawyer, and several other South African geologists formerly gave preference to theories requiring a volcanic origin for the conglomerate.

My examinations of the Vryheid district, fully confirmed later on by researches in several other districts of the Transvaal, and particularly along the Vaal River in Griqualand West, have convinced me that the Dwyka conglomerate and the Ecca shales ought indubitably to be regarded as deposits of glacial origin, probably of Permian age.[8]

Let us first examine what is the position of these deposits in the districts of Vryheid and Griqualand West, which have furnished me with the greater part of my data.

The synchronism of the glacial conglomerates in Griqualand West and the Western Transvaal, in the southern part of Cape Colony, and Natal, and finally in the eastern and southern parts of the Transvaal, might be discussed, and with it the right to comprise all these formations under the name of Dwyka Conglomerate. But it is established that these ancient glacial deposits rest in all instances on formations older than the Karroo System, and that they are overlaid by fluviatile and lacustrine deposits of the Karroo System. This established fact seems to me a sufficient reason for not introducing an element of doubt into the question of the synchronism of the glacial deposits of the different regions of South Africa, a doubt which would only render more intricate an already difficult problem.

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[1] P. C. SUTHERLAND, **62**.

[2] C. L. GRIESBACH, **25**, p. 53.

[3] G. W. STOW, Unedited manuscript.

[4] A. SCHENCK, **56** and **57**.

[5] E. J. DUNN, **17**.

[6] A. H. GREEN, **24**, p. 243 and p. 267.

[7] F. H. HATCH, **27**, p. 100.

[8] Since 1900, when the French text of this paper was written, our knowledge of the Dwyka conglomerate in South Africa has been so much augmented, especially by the results of the geological surveys of the Cape Colony and Natal, and its glacial origin has been proved now from so many places, that I think we have the right at present to take the glacial origin of the Dwyka conglomerate as firmly proved and universally accepted.

The Vryheid district belongs to the so-called *Gebroken-veld* (broken veld), and the difference between the western and the eastern part of the district is very marked. The western part is the continuation of the *Hooge-veld* (high veld), although the high plateau character, so typical still more to the west, is here modified by the erosive action of numerous rivers, which divide the country into strips of elevated ground with an altitude of about 4000 feet above the level of the sea, trending more or less east and west, and separated the one from the other by deep valleys. These valleys broaden, unite, and become more and more numerous proceeding eastward, so much so, that portions of the high land become in consequence entirely divided from the main high plateau. Hence the western portion of the district has the aspect of a high plateau cut up by deep valleys, whilst the eastern portion is a rugged, low-lying country, from which in places there rise mountains whose flattened tops usually attain an altitude approximately the same as that of the western plateau.

The chief watercourses are the Pongola, which forms the boundary between the Vryheid district and that of Piet-Retief, the Umkusi, the Black Umfolosi, and the White Umfolosi. The first and the last are the largest, and flow in deeper valleys than the others.

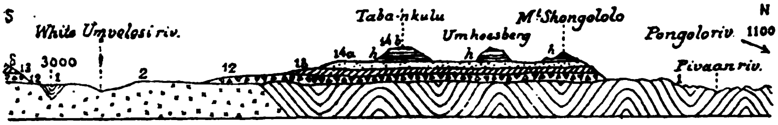

Fig. 14.—Section in the Vryheid district, showing the Karroo System lying on the beds of the South African Primary System. Horizontal scale, 1 : 1,000,000.

High Veld series: 14*b*, Upper Sandstone, 14*a*, Lower Sandstone, 13, Ecca Beds; 12, Dwyka Conglomerate. 2, Old Granite; 1, Barberton Beds and crystalline schists; *h*, Coal horizon; δ, Diabase.

In the Vryheid district there occur formations belonging to the Archæan System and the Karroo System. The Archæan System is represented by crystalline schists, the Barberton series, and masses of granite.

The beds of the Archæan System are always tilted, sometimes they even stand vertical, but on the whole they are less tilted than is the case in the Barberton district.

The rocks of this system only come to light where erosion has removed the whole of the Karroo beds, which are superimposed horizontally and unconformably. Consequently these oldest formations should be sought in the first place in the large valleys of the Pongola and the White Umfolosi, although they are also found beyond these valleys cropping out at several points through the covering of the overlying horizontal Karroo strata.

The Karroo System is very easily studied in the numerous gorges of the watercourses which cut into it and give very fine natural sections, for example, in the Hlengeni gorge, on the northern flank of the Ingomo Mountain.[1] The comparative study of these sections, which disclose all the characters of the Dwyka conglomerate and of the Ecca beds enumerated above, has led me to the following conclusions:—

The unstratified Dwyka conglomerate must be considered as a ground moraine in the proper sense of the word, the boulder-clay of a gigantic glacier or ice-cap of Permian age, whilst the stratified Dwyka represents stratified deposits laid down by the streams of water arising from the melting of the glacier and running beneath and from the front of the ice. Finally, the Ecca beds represent silts carried by the glacial streams from the melting ice and accumulated in the lakes of the moraine landscape, principally during the period of melting and receding of the glaciers or ice-cap. The Permian Ecca beds can then, in regard to their genesis, be compared with the European deposits of diluvial loess which, due allowance having been made for alterations and replacement to which they have been subsequently subjected, appear to have originated from the glacial silt deposited by the streams of water flowing from the melting ice during the period of receding of the Quaternary glaciers.

The following arguments supporting this theory may be mentioned here:—

1. The surface of the rocks of the Barberton series is planed, polished, and grooved in one direction wherever it was directly overlaid by the Dwyka conglomerate. The direction of these striæ is really that of the movement of the glacier ice-cap, whose ground moraine planed and grooved the surface of the underlying rocks. This moraine, solidified later, has become the Dwyka conglomerate. I myself have observed these glacial striæ at the following points:—

(*a*) On the farm Doornpan [177] (district of Vryheid), in the gorges of several streams, which, rushing from the Hlangweni or Gotshe Mountain (fig. 13), have cut through the Dwyka conglomerate and have reached the surface of the highly tilted hard clay-slates and shales belonging to the Barberton series (see fig. 15 and Pl. I.).

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[1] See G. A. F. MOLENGRAAFF, **38**, Pl. II., opposite p. 100.

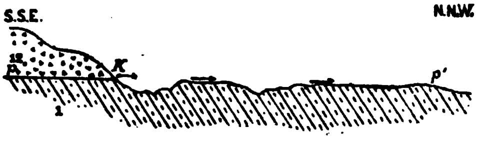

FIG. 15.—Dwyka conglomerate (12) lying on the Barberton beds (1) (farm of Doornpan [177], district of Vryheid). The surface of the quartzitic clay-slate of the Barberton series is polished and striated in the direction indicated by the arrows. The polish and the striæ are most distinct at the point *K*, where the underlying schists, near the wagon road from the Hlangweni Mountain to the Pongola Goldfields are just appearing from underneath the Dwyka conglomerate. The plane *pp'* does not correspond either to the planes of stratification or to the cleavage planes of the schists.

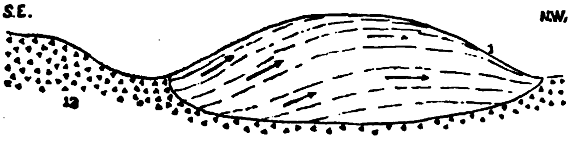

FIG. 16.—*Roche moutonnée* [quartzite of the Barberton series (1)] emerging from the underlying Dwyka conglomerate which surrounds it. The quartzite is polished and striated in the direction indicated by the striæ and the arrows. (Farm of Nauwpoort [556], Vryheid district.)

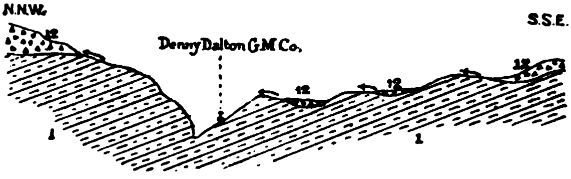

FIG. 17.—Dwyka conglomerate (12) resting on the undulating surface of the Barberton beds (1) (property of the Denny-Dalton gold-mines). The surface of the schistose sandstones, conglomerates, and quartzites of the Barberton series under the conglomerate is polished and striated in the direction indicated by the arrows.

(*b*) On the farm Nauwpoort [556], near the Black Umfolosi in the Vryheid district, where some small hills, composed of a quartzite of the Barberton series, project through the Dwyka conglomerate which completely surrounds them (fig. 16). These hillocks, some fifty feet in height, have their surface so perfectly polished that the sun is reflected from it as by a convex mirror. It is impossible, climbing these little hills on horseback, to get a safe foothold on their surface. They are typical *roches-moutonnées*, the whole surface of which is not only completely polished, but also grooved by numerous fine parallel striations. It is very interesting to note that the grooves on the hillocks are not confined to one side only, that from which the pressure came, but that the whole surface presents the same appearance. This proves that the grooving and polish was produced by a moving body not only powerful and heavy enough to polish and groove the hardest

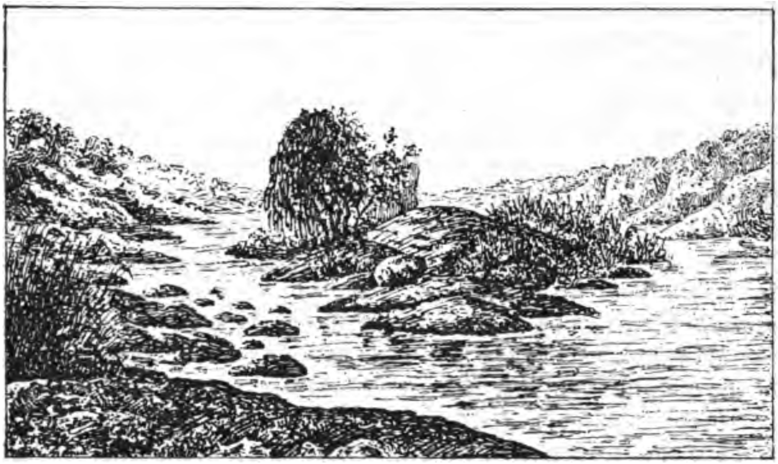

FIG. 18.—*Roches moutonnées* polished and grooved under the Dwyka conglomerate, some remnants of which still cover it. Island in the Vaal, near Riverton (Griqualand West).

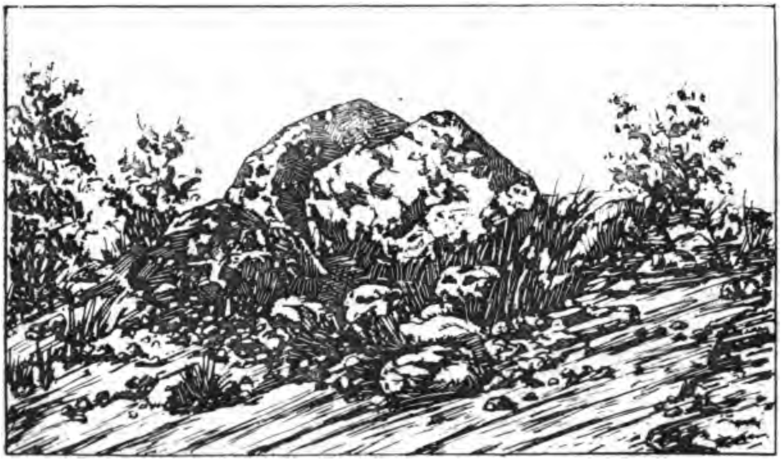

FIG. 19.—Morainic landscape, near Riverton, the rocks of diabase of the Vaal River System, cropping out from under the Dwyka conglomerate, are very clearly polished and striated.

rocks, but also sufficiently plastic to follow the undulations and irregularities of the country over which it passed. Glaciers of great thickness are the only known bodies which answer to all these conditions.

(*c*) On the farms of Vlakhoek [548] and Tusschenbeide [411] (Vryheid district), near the Denny-Dalton gold-mine, where very distinct striations occur on the polished surfaces of the quartzites and quartzitic sandstones of the Barberton series (fig. 17).

(*d*) On the farm Blauwbank [78], where the surface of an amphibole granite is found polished and striated.

(*e*) Along the Vaal, near Riverton, in Griqualand West. The surface of a diabase (passing into an amygdaloidal diabase) belonging to the Vaal River System is polished and striated wherever it appears from under the overlying Dwyka conglomerate. The sketches (figs. 18 and 19) made on the spot in 1899 give an idea of the morainic landscape of these localities. Stow had already, in 1880, observed the glacial phenomena in Griqualand West, and the spot represented in the sketch above seemed so typical to him that he had also sketched it from the same point.[1] In the little island in the middle of the Vaal the perfectly polished diabase rocks are seen appearing as typical *roches moutonnées* still partially covered by remnants of Dwyka conglomerate *in situ*. The glacial striæ on these rocks follow a direction almost at right angles to that of the flow of the river, and the fact that Stow observed and sketched these islets and grooves on the rocks in 1880, absolutely in the same conditions as I myself did in 1899, proves that the result of erosion caused by the waters of the Vaal on these markings during nineteen years is not appreciable. In all the localities cited, in the Vryheid district and in the province of Griqualand West, I have never failed to find the Dwyka conglomerate *in situ* in the immediate vicinity of the polished and grooved surfaces of the older underlying rocks, and the striæ are clearest and most distinct at the immediate junction of the two formations, that is to say, where the underlying rocks[1] are just appearing from under the Dwyka.

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[1] G. W. Stow, in a posthumous manuscript, still unpublished, has described in a most exact manner the glacial phenomena in the province of Griqualand West. I have had the opportunity of comparing on the spot several of these descriptions and plans, and have been convinced of their accuracy. Although several of the views and conclusions of this author can no longer be accepted, among others the theory of a second glacial period of Quaternary age in Africa, see **59**, p. 534, his remarkable researches are none the less of the greatest interest. This unpublished manuscript belongs to the *Geological Society* of South Africa. In March 1903 I had an opportunity of making some researches on the ground of the New Vaal River Estates Co., near the confluence of the Vaal and Harts rivers, and found there most magnificent examples of grooved and polished surfaces on the diabase and amygdaloidal diabase directly underlying the Dwyka conglomerate, the majority of these having been already exactly located on the maps accompanying Stow's manuscript.

Mr. Dunn (see E. J. Dunn, **17**, p. 9) has likewise found glacial striæ on a hard clay-slate, immediately underlying the Dwyka conglomerate near the confluence of the Vaal and Orange rivers. In discussing the origin of these striations, he says: '*It seems probable that this surface formed part of the shelving floor of the lake, and that icebergs were driven ashore by the wind, thus scratching and grooving the rocks; the melting of the icebergs would cause the stones, earth, etc., to be deposited on the ice-scratched floor, thus forming the conglomerate.*' This theory seems to be untenable; the fact alone that these striations are found on the underlying rocks and at points dozens of miles apart, all in the same direction, and consequently forming a single uninterrupted system of striæ, is absolutely incompatible with the theory of 'icebergs' driven by the wind.

The direction of the striæ in the Vryheid district, at Doornpan and in several neighbouring localities within a radius of a mile, is S. 28° E., at Nauwpoort S. 56° E., at Tusschenbeide, near the Denny-Dalton mine, S. 33° E. In the province of Griqualand West, on the ground of the Vaal River Estate Co., it varies from N. 37 E. to N.E.-S.W.

In Griqualand West the general direction of the movement of the ice has been from N.E. to S.W., and the Dwyka conglomerate contains in abundance blocks of a very typical quartz porphyrite which outcrops in the regions situated more to the N.E., for instance in the districts of Bloemhof and in the Makwassie Hills (district of Wolmaransstad). In the Vryheid district the direction of the movement of the Permian ice-cap is not yet definitely determined, but my observations are in favour of a movement from S.E. to N.W.[2]

Griesbach,[3] as well as Sutherland,[4] has observed grooves under the Dwyka conglomerate on the surface of sandstones, from the Infumi River and other localities in Natal, which he considered to be very probably equivalent to the Table Mountain sandstones in Cape Colony; but he had no definite opinion regarding the direction of movement of the Permian glaciers in Natal.

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[1] In our case, in the Vryheid district, it is the Archæan System, and in Griqualand West the Vaal River System. Stow has also observed in Griqualand West glacial striæ on quartzites belonging to the Transvaal System, and very probably to the Black Reef series (unpublished manuscript).

[2] Since 1900 I have altered my opinion about this question, as I gained more information about the probable origin of several rocks found in the Dwyka. Rocks, for instance, which I have found in the Dwyka conglomerate in the Ermelo district, I know now belong to the Plutonic series of the Bushveld, and similar finds made later from the vicinity of Amsterdam were confirmed by Dr. Corstorphine. Thus I feel pretty certain now that the ice movement in the Vryheid district must have been from N.W. to S.E.

[3] C. L. GRIESBACH, **25**, p. 60, says: '*Grooves, quite similar to those in the Alps, occur in great abundance on the sandstone of the Infumi River, about twenty miles south of Durban.*'

[4] P. C. SUTHERLAND, **63**, p. 515, says: '*The old sandstones which lie immediately beneath the boulder-clay, have their upper surfaces, in many instances, deeply grooved and striated, as if a semiplastic substance, containing hard and angular fragments, had been passed over with considerable pressure.*'

2. There exists as to structure and composition a perfect analogy between a boulder-clay and the Dwyka conglomerate. Only, in the latter the argillaceous cement[1] is indurated, silicified, and more or less recrystallized, which, regard being had to the age of the Dwyka, is easily explicable by mechanical and chemical action under the pressure of the superimposed strata of the Upper Karroo series. In many places where the Dwyka has been exposed for a long time to atmospheric action it is once more transformed[2] by decomposition into a kind of boulder-clay, and all differences disappear. The Dwyka conglomerate everywhere contains an abundance of striated pebbles. I have found them in many localities of the Vryheid district, on the farm Athole [85], near Amsterdam (district of Ermelo), in the neighbourhood of Vereeniging and near the Modderfontein gold-mine (Heidelberg district), at several points of the Bloemhof district, and beyond the frontier of the State along the Vaal River below Fourteen Streams, and in many other places in Cape Colony and in Natal.

3. Alternating stratified and unstratified deposits occur in the Dwyka conglomerate, as is the case in all true glacial deposits. Whereas the unstratified deposits, the boulder-clay, represent the ground moraine *stricto sensu*; the stratified deposits are formed by streams from the melting ice which run at the bottom of the glacier and escape at the front of it. The larger the glacier the more complex and diversified must be the system of the subglacial streams. They shift their course like all other streams; they disappear or increase in size and number with the decline

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[1] In the unaltered Dwyka the cement shows by macroscopic examination a texture feebly crystalline, very different from that of a clay, which has without doubt suggested to some of the observers the idea of the eruptive origin of this rock. But on examining this cement under the microscope, it is evident that it must originally have been a mud containing numerous small angular or semi-angular fragments of various rocks and minerals with a preponderance of quartz, and that the originally perfect clastic texture has been largely modified by phenomena of recrystallization.

[2] In the plains of the Karroo, in Cape Colony, where the climate is extremely dry, the Dwyka conglomerate, though exposed for a long period to atmospheric action, scarcely shows signs of alteration or of decomposition.

and growth of the ice, and the final result is that, after a period of prolonged glaciation, deposits have been formed in which unstratified portions must in many places alternate with the stratified portions. It is evident that towards the centre of a huge area of glaciation (ice-cap or continental glaciation) the glacial deposits will be very poor in, or entirely devoid of, stratified portions, whereas towards the outskirt the stratified deposits will increase in area and bulk, so that in many places they may predominate over the unstratified true boulder-clay. Moreover, the periodical forward and backward movement of the ice suffices of itself to produce in every instance alternations of stratified and unstratified glacial deposits in the outer zone of the glaciated area.

These stratified deposits will be in places rich in pebbles more or less water-worn, at other times they may be quite devoid of pebbles. Needless to say that all the characteristics of fluviatile deposits may be found in these deposits, as for example false bedding and the rapid succession of beds of coarse gravel and of fine mud. The deposits due to glacial waters differ, however, from the deposits of ordinary rivers in that they are chiefly composed of a very fine silt, produced by the trituration of the rocks in the ground moraine. Occasionally blocks, sometimes of huge size, may be found in this fine silt, these having tumbled down from the lateral, medial, or terminal moraines through crevices in the ice.

All these characters are exhibited abundantly and with perfect distinctness in the stratified parts of the Dwyka conglomerate, and can be studied with wonderful clearness in the numerous natural sections provided by the gorges of the Vryheid district.

Besides, it is often observed that a deposit of stratified Dwyka, intercalated between two beds of unstratified Dwyka conglomerate, is in its upper part dislocated and contorted, a phenomenon which can be attributed to the pressure exerted by the ground moraine which slid on these beds and is always found lying above in the form of a bed of unstratified conglomerate. It is a phenomenon absolutely analogous to that observed under the ground moraines of the glaciers of the Quaternary ice-age in Scandinavia and Scotland, and known under the name of *contorted drift.*

4. Further, in the Dwyka conglomerate are found blocks derived from rocks outcropping not far away, mixed with other fragments of rocks coming from distant points. The origin of some of the boulders is obscure, as they belong to types of rocks not yet found *in situ* in South Africa.

The Dwyka conglomerate has often a local character through the preponderance of débris from a certain rock over the others, which can be explained as follows. Say, a glacier crosses in its track the outcrop of a certain rock, which we shall designate by A; this glacier will detach pieces of the rock A and entangle and mix them with the other débris in the ground moraine. It is obvious that the ground moraine will, upstream from the point of outcrop of the rock A, be entirely free from blocks of it; whereas downstream from that place of outcrop it might carry in its mass a proportion of fragments of this rock A, great enough to give the ground moraine a local character. I have often observed such a local character in the Dwyka conglomerate; at Vereeniging, for instance, where the Dwyka conglomerate rests on the dolomite of the Transvaal System, which outcrops a short distance off, this conglomerate abounds in striated pebbles of dolomitic limestone which I have never found in the Dwyka conglomerate of the Vryheid district. These local characters afford one of the best means of determining the direction of movement of the Permian ice. Thus, as we have already seen, the presence of numerous blocks of quartz porphyrite with oligoclase in the Dwyka conglomerate along the Vaal, below Fourteen Streams, proves that the direction of movement there must have been from N.E. to S.W. Mr. Dunn,[1] in 1886, gave a striking example of the local character sometimes assumed by the Dwyka; he writes: '*East of the Doornberg range (Griqualand West) there is a complete absence of the yellow jasper and altered crocidolite, of which these hills consist, in the Dwyka conglomerate, while to the west of this range they are abundantly represented, mingled with the far-borne material.*' An ice-sheet having moved from east to west across this Doornberg range, would have exactly produced these phenomena, but in opposition to Mr. Dunn I cannot see how the action of floating ice could possibly have given similar results.

5. The material of the Ecca beds is, in its composition, perfectly identical with the cement of the Dwyka conglomerate. It is, in fact, a mud or silt, now indurated, transported by glacial waters and laid down, it may be, in the large lakes which characterized the morainic landscape; it may be in stretches of country inundated by the torrential waters during the period of melting and receding of the ice-sheet. Large boulders, sometimes though rarely met with in the Ecca shales, may have been carried by ice-floes on these streams and lakes.

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[1] E. J. Dunn, 17, p. 9.

6. Accepting the glacial theory, one can readily explain the erratic distribution of the Dwyka conglomerate and Ecca beds. It would be difficult to explain otherwise how, in an area entirely free from faults, the Dwyka could be found at widely varying altitudes and in a normal position in spite of this difference of elevation. With the glacial theory, this difficulty disappears as soon as one admits that a large glacier or ice-cap has scored and grooved the surface of the underlying rocks, while remaining sufficiently plastic to follow the irregularities of the ground, moulding them into hog-backed mounds or *roches moutonnées*, polished and grooved, and at the same time depositing its ground moraine at very different altitudes and yet in a normal position. It would also be difficult to explain otherwise how the thickness of these formations can vary so greatly and how, in some places, the Dwyka conglomerate, or the Ecca beds, or it may be both, can be absent beneath the overlying strata of the Karroo, even in districts where the Lower Karroo generally occurs highly developed. The explanation is simple, if it be remembered that under the glaciers and in the areas abandoned by them as they recede, the effects of erosion may preponderate at one spot over those of sedimentation, whilst in a neighbouring locality the contrary may occur.

Summarizing, we assume that the Dwyka conglomerate and the Ecca beds, that is to say, the Lower Karroo, are of glacial origin, and this origin, we do not doubt, will afford an explanation of all the features of the beds of the Lower Karroo formation. But one must expect to find the effect of glaciation on a much grander scale than in the *diluvium* of the northern hemisphere. It is certain that the existence must be admitted of an ice-cap of great thickness and of very great extent, as well as a very long duration of the ice period, to be able to explain the enormous thickness[1] and the greatly diversified development of the Permian glacial deposits of South Africa.

The problem of the ice-age in South Africa, during the Permo-Carboniferous period, is of more than local interest. Geological research in India and in Australia have proved that there exist in these countries formations strikingly analogous. In India the

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[1] The Dwyka conglomerate in the Cape Colony attains a thickness of more than 1300 feet, but there, after Dr. Corstorphine's researches, the Dwyka does not represent a true ground moraine, but a drift deposit. In the Vryheid district, where the Dwyka conglomerate represents indisputably a ground moraine, the thickness averages about 300 feet.

Gondwana System can be identified with the Karroo System. At its base are found the *Talchir Conglomerates*, which present all the characteristics of a boulder-clay and are absolutely comparable with the Dwyka conglomerate. The older underlying rocks (*Vindhyan-limestones*) have been found polished and grooved in several localities, among others near Chanda, in the central provinces of India.[1] The *Talchir Shales* are associated with this conglomerate, and display all the characteristics of the Ecca beds. Like the Ecca beds, they are nearly always devoid of fossils. Overlying these glacial deposits are sandstones, similar to those of the Upper Karroo, in which is found a *Glossopteris* flora, very analogous to that of the Karroo.

In Australia the traces of an ancient ice-age are not less clear, and the glacial deposits, which are associated there, as well as in the Salt Range of India, with sediments containing marine fossils, have established that the glaciation of the two continents was contemporaneous, and occurred during the later period of the Palæozoic Era. And the general affinities between the Karroo System and the Gondwana System are so evident that one may go further and assume that the Permian glacial deposits of South Africa, of India, and of Australia are contemporaneous.

The glacial deposits of the Lower Karroo have, without doubt, covered all the southern half of the Transvaal.[2] In the east they are to-day invisible because they are covered by the strata of the Upper Karroo, and they only crop out on the escarpment of the high plateau towards the east, that is, in the eastern portion of the districts of Ermelo and of Carolina and in the districts of Piet-Retief and of Vryheid, where they can be easily studied. In the central Transvaal, the Upper Karroo diminishes greatly in thickness and the Lower Karroo outcrops here and there, as, for example, near Vereeniging and Meyerton, in several localities around Heidelberg and Boksburg, on the farms Zuurbekom [9] and Syferfontein [32], etc. Finally, in the western districts, the Upper Karroo being absent, the Lower Karroo frequently comes to light. Nevertheless, the Lower Karroo has in this region been in great part removed by denudation and, in the places where it still exists, it is often hidden by more recent superficial deposits, such as calcareous tufas and wind-blown deposits of slight thickness (3 to 12 feet).

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[1] R. D. Oldham, **48**, p. 160.

[2] I have not found deposits of the Lower Karroo north of 26° 40′ south latitude. It is true that Mr. Dunn has indicated, on his geological map of the Transvaal, the Dwyka conglomerate much further north, in the Waterberg district, and even in the Blauwbergen, beyond the Tropic of Capricorn, but my researches have proved that the conglomerates in the Waterbergen are not glacial, but form the base of the Waterberg sandstone, and I have good reason to believe that the conglomerates of the Blauwbergen, which I have not visited, are identical with those of the Waterbergen. See E. J. Dunn, **18**.

The Dwyka conglomerate has a certain economic importance in the vicinity of Vereeniging, where the cement, after having been separated from the boulders which it contains, is utilized for the manufacture of very refractory bricks, excellent for the construction of furnaces and houses.

2.—UPPER KARROO

The beds of the Upper Karroo have nearly always an almost perfectly horizontal and normal position. Sometimes they are slightly tilted; they are never folded, although they are often enough dislocated by faults which have in places subdivided the mass of the Upper Karroo formation into blocks in which the corresponding strata, while retaining their horizontal position, are found at different levels.

The Upper Karroo consists of sandstones, arenaceous clay-shales, carboniferous shales, and seams of coal.[1] False bedding prevails all through the system, and is particularly marked in the sandstones.

Numerous sheets of diabase (dolerite) are interbedded quite conformably between the other strata of this formation. In the sheets of diabase, most frequently olivine diabase, a very distinct columnar structure is generally observable. In addition, the whole system of strata is intersected by a perfect network of dykes of diabase of the same type. The diabase of the Karroo can be easily distinguished from the older diabases. The ordinary type of granular diabase of the Karroo is known to the mining community of the Transvaal under the name of *Dolerite.*[2]

COAL HORIZON.—In the Upper Karroo of the Transvaal, to which I have provisionally given the name *High Veld Series*, there occur seams of coal which, on account of the constantly increasing development of the mining industry of the Witwatersrand, an industry requiring large supplies of fuel, constitute an invaluable source of wealth to the country. They are generally non-cooking and unsuitable for use in foundries. Sometimes their percentage of sulphur renders them liable on exposure to the air to spontaneous combustion. They often contain incombustible material in greater or less quantity. In short, these coals are chiefly suitable for steam-raising and domestic purposes. The seams are very thick, and the amount already worked is trifling. It is quite certain that the collieries of the Transvaal will be able to supply the requirements of the whole of South Africa during at least some hundreds of years.[1]

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[1] There occur rather rarely marly beds in which the lime is concentrated in nodules. Near Standerton I found in one of these nodules a wing of an Orthopterous insect, very well preserved.

[2] E. COHEN has given a detailed petrographical description of a good number of these diabases of the Upper Karroo, belonging for the most part to the lower or Beaufort division, **9**, p. 220.

The coal-seams of the Transvaal should apparently be regarded as vegetable alluvium deposited by torrential streams. The fragments of trunks of *Sigillaria* and of stems and leaves of various kinds of *Glossopteris* play an important part in the composition of the coal itself. The roofs of the coal-seams contain, as can be seen in the coal-mines of Vereeniging, numerous trunks in horizontal position. I believe that there may be admitted for the coals of the Transvaal—at least for the greater part of them—a process of formation analogous to that which MM. Grand'Eury and Fayol have assumed for the coal basins of the centre of France.

From present knowledge it is permissible to assume that there exists in the Upper Karroo of the Transvaal only one geological level containing beds of workable coal. It may be granted that this level is situated on the high plateau at an altitude varying between 4000 and 6000 feet. At a first glance this coal horizon seems to occur at very irregular points in the order of strata of the Upper Karroo. At Vereeniging, at Meyerton, and in the neighbourhood of Boksburg, for instance, the Dwyka conglomerate is situated almost directly under the seams of coal, whilst in the Vryheid district a succession of sandstones and shales from 600 to 1000 feet thick separates them from the Lower Karroo.

In the Upper Karroo of the Vryheid district and on the Qudeni Hills in Zululand two series of sandstone can be distinguished. The lower series is composed of heavy beds of bluish-grey sandstone, becoming yellowish on exposure. In course of decomposition these sandstones acquire a spheroidal structure, often very distinct. There are frequently found in these sandstones fragments of petrified wood; near Umkusiberg, on the farm of the same name, petrified trunks and branches of trees lying in different directions occur in abundance. Impressions of fragments of vegetable origin, leaves, stems, etc., and very thin veinlets of coal are frequent enough in these sandstones, but beds of workable coal are entirely wanting.

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[1] In 1898 the annual production was estimated at 2,000,000 tons. In the year ending 30th June 1902 the production was 1,134,871, and in the year 1902-3 it was 1,969,089 tons of 2000 lbs.

The sandstones of the upper series are lighter in colour, with a well-developed cement between the quartz grains, which is rich in kaolin. These sandstones pass sometimes into arkoses. Clay-shales, carbonaceous shales, and workable seams of coal are interstratified with these sandstones.

The position of the whole Karroo System in the Transvaal becomes more comprehensible as soon as one bears in mind that the whole of the system thins out in going from east to west. Thus the sandstones, shales, and diabases which underlie the beds of coal in the Vryheid district no longer exist in the centre of the Transvaal. Similarly in the central part of the country only a limited number of beds of sandstone, clay-slates, and diabases occur above the coal-seams, whilst in the east a great thickness of strata rests on the coal formation. It is of immense economic importance that the coal-seams are nearly as well developed in the central as in the eastern districts.

The Upper Karroo forms in the south-east part of the Transvaal only an uninterrupted formation, joining the extensive area of the Karroo System in the Orange River Colony. The subsoil of the districts of Wakkerstroom and of Standerton is entirely composed of it, whilst that of the districts of Vryheid, Utrecht, Carolina, Ermelo, Middelburg, Pretoria, and Heidelberg only partly so. Besides this great connected area there are found towards the north and west numerous small patches of the Karroo System lying unconformably on rocks of the Primary System or on those of the Transvaal System. Thus patches of the Karroo System occur in the South Rand coalfield and in the neighbourhood of Boksburg, superimposed on rocks of the Primary System, that is, on those of the Hospital Hill series or on those of the Witwatersrand series; in the vicinity of Vredefort on the ancient granite; at Vereeniging and at Meyerton (Heidelberg district), at Zuurbekom [9] and at Syferfontein [32] (Krugersdorp district), and at Stilfontein [381] (district of Potchefstroom) on the dolomite; in the neighbourhood of Belfast on the Pretoria series; at Waterval, to the north of Pretoria, on norite and syenite; further north still at Hamanskraal (Pretoria district) and in some localities of the

Middelburg district on the red granite. To the west of Klerksdorp the Upper Karroo has not yet been found.

The patches of the Karroo System found on the dolomite deserves special mention. They stretch in a curved line on the west, north, and east of the Gatsrand Mountains, which consist of beds of the Pretoria series. They are situated, as can be very easily proved on the properties of Syferfontein and Zuurbekom, in flat ground, and are surrounded on all sides by the outcrops of rocks of the Dolomite series. In reality, these patches are portions of the Karroo System which have sunk into the strata of the underlying Dolomite series. These subsidences have been caused by the collapse of the arch of caverns in the dolomite. The Karroo System, which formerly covered the whole of this ground, was later on removed by denudation and erosion, and has now entirely disappeared, except in those localities where, from its lower position, due to subsidence, it could escape from the influence of denuding agencies. Needless to say, this subsidence has modified the normal position of the beds of these patches, and explains how in the sunken block of Syferfontein there occurs a thick bed of coal[1] tilted at an angle of at least 40°. These patches, which are consequently situated on a level with the dolomite, have another point of economic importance. They constitute reservoirs of water in subterranean communication with the inexhaustible underground reservoirs of the dolomite formation: consisting of sandstone, they offer greater facilities for the construction of wells and for the deep boring necessary to tap the underground waters. At Zuurbekom shafts have been sunk in such an islet of the Upper Karroo sandstone existing at this point, and have been provided with pumping plant of great capacity. This installation provides 4,000,000 gallons of absolutely pure water daily for the supply of the town of Johannesburg. Up to 1897 the water provided by the water companies of Johannesburg was insufficient and impure; the discovery and the tapping of the magnificent water supply of Zuurbekom have effected a considerable amelioration in the sanitary condition of the town, a benefit for which it is indebted to the practical application of geological observations made in this area by Mr. D. Draper.[2]

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[1] The discovery of the fine bed of coal at Syferfontein is of great importance, because the distance separating it from the mines of the West Rand to the south of Krugersdorp does not exceed fifteen miles, whilst at present these mines have to obtain their fuel supply from distances at least three times as great.

[2] D. Draper, **15**, p. 139.

The following may be accepted as a feasible theory as to the mode of formation of the Upper Karroo. After the retiring of the glaciers or the ice of the Permian glacial epoch a moraine-covered landscape occupied this region, and the Dwyka conglomerate was in great part covered and on all sides surrounded by the Ecca beds. Denudation speedily exerted its destructive power, and the deposits of the Lower Karroo were, without doubt, in places completely removed and redeposited. But, at the same time, a series of sedimentary deposits began to be formed, constituting the Upper Karroo. These fresh-water deposits accumulated partly in the channels of flowing water and partly in lakes. They consisted of sandstones and clays exhibiting false bedding, and sometimes also of beds of vegetable débris carried onwards by torrential currents, beds which have become seams of coal.

Originally these sediments were deposited in depressions of glacial origin, thus forming limited and isolated patches. But in process of time, the depressions having filled, the Upper Karroo formation spread out uninterruptedly over a wide area, embracing a large part of South Africa. A small portion only of the enormous development of the Karroo System has remained in existence till to-day, the remainder having been destroyed and removed during the period of denudation subsequent to this formation, a period which still continues to the present time.

GREAT EASTERN FAULT.—A very remarkable dislocation affords indubitable proofs that the strata of the Karroo System have formerly had an easterly extension far beyond the present limits of the Transvaal, a fact which is, moreover, deducible from the abrupt manner in which the beds of the Karroo System terminate in the escarpments on the eastern edge of the high plateau of the Transvaal and the Orange River Colony.

In the eastern part of the Transvaal there occurs, following a north and south direction, a large fault, which may be regarded, from a geological point of view, as the eastern limit of the continental plateau of South Africa. I have designated this dislocation the GREAT EASTERN FAULT.[1] The country to the east of this fault has sunk relatively to that on the west at least 5000 feet. This fault is situated at an average distance of ten miles to the west of the frontier of the Portuguese colony of Mozambique. It is always parallel to the Lebombo chain of mountains, which it follows, and it may very probably be regarded as the northern prolongation of the great fault, described by Griesbach, which in

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[1] See G. A. F. MOLENGRAAFF, **37**, p. 138 and Pl. I.

Natal has lowered the strata of the Lower Karroo formation to the level of the sea, strata which in the neighbourhood of Pietermaritzburg attain an altitude of 2000 feet. In the Transvaal the western side of the fault always consists of the old granite or of schists of the Archæan System, whilst the eastern side consists of sandstones, clay-shales with *Glossopteris*, and beds of coal belonging to the Upper Karroo, with an inclination of 15° to 20° towards the east. These deposits, perfectly identical with those of the Upper Karroo of the high plateau, are covered conformably by the Lebombo rocks. The latter are flows of volcanic rock, the lower part of which, outcropping around Komatipoort on the western slope of the Lebombo Mountains, consists of rocks of the diabase and the melaphyre families with a preponderance of amygdaloidal types.

It is worth noting that among these amygdaloidal rocks, near the bridge of the Selati railway over the Crocodile River, types occur characterized by a marked elongation of its amygdules closely resembling the amygdaloidal rocks of the same type of the Maluti Hills in the Orange River Colony described by Cohen.[1] The latter are found at the top of the upper stage of the Upper Karroo. Our knowledge of the strip of Karroo country along the Lebombo range is at present too fragmentary to allow us to judge if this resemblance be purely accidental or not.

In the upper portion of these flows of volcanic rocks, that is to say, in the Lebombo range itself, more acid types belonging to the felsophyre group prevail. Amongst these, scoriaceous types occur, enclosing in their gaseous cavities beautiful crystallizations of calcite and zeolites. Some varieties of these acid rocks form excellent building-stone. These flows of ancient lava dip 10° to 30° to the east, an inclination which corresponds to the dip of the sandstone strata of the underlying Upper Karroo formation. All these rocks exhibit a very distinct flow-structure. A detailed microscopical examination of the numberless varieties of eruptive rocks to be found in the Lebombo range is not yet made, and I have classified them provisionally under the one name, 'Lebombo rocks.' The structure of the chain seems to be very uniform over long stretches, judging from the description of the rocks observed by Mr. Cohen,[2] who crossed the Lebombo range in 1873, near Matalha Poort, twelve miles south of Komatipoort, and from specimens which I have received from Pongola-poort, a point situated 127 miles still further south. There occur at these two points the same classes of rock which I have observed in the fine railway cutting between the stations of Komatipoort and Inkomati.

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[1] E. Cohen, 7.

[2] E. Cohen, 8, p. 67-91, gives an excellent petrographical description of the types of melaphyres and felsophyres of the Lebombo, which he observed in travelling across the range.

In Cape Colony it has been customary to subdivide the Upper Karroo into the *Beaufort beds* (Schenck and Feistmantel) or *Karroo beds* (Green) as the lower, and the *Stormberg beds* as the upper division. Following the classification adopted by Mr. Dunn, the Stormberg beds are subdivided as follows in descending order:—

4. VOLCANIC BEDS.
3. CAVE SANDSTONE.
2. RED BEDS.
1. MOLTENO BEDS.

All the workable seams of coal in Cape Colony are found in the Molteno beds. These carboniferous beds are distinguished in Cape Colony by the presence of the flora, *Thinnfeldia odontopteroïdes, Sphenopteris elongata, Podozamites elongata, Baiera Schencki, Pecopteris,* etc., and by the absence of *Glossopteris.* This flora has thus a more recent character than that with *Sigillaria* and *Glossopteris,* notably *Glossopteris browniana* and *Gl. indica,* which abound in all the known coal-measures of the Transvaal, but it is, according to O. Feistmantel,[1] by a flora exactly identical with the latter that the Beaufort beds are characterized. It follows from this that the coal-measures of the Transvaal, which I have classified under the name High Veld series (*Hoogeveld series*), cannot be correlated with the Stormberg beds, as indicated on the maps published by Dunn and Schenck. The High Veld series represents the lower division of the Upper Karroo, and ought to be considered as equivalent to the Beaufort beds of Cape Colony.[2] R. Zeiller[3] has established this indisputably by palæontological proofs, and my researches of late years have convinced me that the theory of Schenck, that the Beaufort beds were overlapping the deposits of the Lower Karroo towards the north, and the Stormberg beds were similarly overlapping the Beaufort beds towards the north, ought to be rejected. In the Transvaal, on the contrary, the Upper Karroo is exclusively, or at least almost solely, represented by its lower division.[4]

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[1] O. FEISTMANTEL, **19.**

[2] In 1894 I discussed this question and expressed the opinion that the coal-measures of the Transvaal ought to belong to a stage or division of the Karroo more ancient than the Molteno beds (**35,** p. 238).

[3] R. ZEILLER, **65,** p. 374.

[4] G. A. F. MOLENGRAAFF, **41,** p. 215.

This view has been confirmed since, and may be taken to be fully accepted at present. But the discovery that the coal-seam at Vereeniging not only rests on Dwyka conglomerate but is also covered in places by glacial conglomerate and allied deposits induced Dr. Corstorphine[1] to support a view expressed formerly by Mr. E. J. Dunn, and consider the coal of the Transvaal and the neighbouring portions of the Orange River Colony and Natal as of Ecca age. This would place our High Veld series in the Lower Karroo. Believing that the development of the coal formation at Vereeniging is a rather exceptional and local one, and, especially for stratigraphical reasons, I cannot yet endorse this opinion, and prefer to restrict the name Lower Karroo to the true and easily recognisable glacial deposits, Dwyka conglomerate and Ecca shales.

I rather believe that the facts, as far as they are known at present, are justly interpreted by accepting the following divisions[2] of the Karroo System in the Transvaal:—

UPPER KARROO: Fluviatile and Lacustrine.
Stormberg beds, not developed in the Transvaal, containing coal-seams in the Cape Colony.
Hoogeveld series, probably Beaufort beds; containing coal-seams in the Eastern Transvaal; thins out towards the west.

LOWER KARROO: Glacial and Interglacial.
Ecca shales, very well developed in the Eastern Transvaal, thinning out towards the west, and not developed at Vereeniging.
Dwyka conglomerate, containing locally (interglacial) sandstones, with coal-seams at Vereeniging.

As to the age of these deposits, the researches of Messrs. Seward[3] and Zeiller have established that the lower division of the Upper Karroo in the Transvaal may be regarded as Permo-carboniferous.

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[1] G. S. CORSTORPHINE, 11, and A. R. SAWYER's Discussion of Dr. Corstorphine's Paper, *Trans. of the Geol. Soc. of South Africa*, vol. vi. p. 34, 1903.

[2] G. A. F. MOLENGRAAFF, Discussion, etc., *ibid.*, p. 45.

[3] A. C. SEWARD, 58, p. 92.

DEPOSITS MORE RECENT THAN THE KARROO SYSTEM

Up to the present no sedimentary deposits more recent than those of the Karroo System have been found in the Transvaal, and the whole configuration of the country proves that a lengthened period of denudation has reigned.[1] That does not exclude the occurrence, here and there, of recent superficial deposits, such as alluvium, beds of limonite, æolian drifts, calcareous tufas, etc., which, however, have never more than a local importance.

Among the igneous rocks it is very certain that the diamondiferous rock is more recent than the Karroo deposits, because in the Orange River Colony it has forced its way through the strata of the Upper Karroo. In 1897 an outcrop of rock, identical with the well-known *kimberlite* of Kimberley, was found on the farm Rietfontein [501] in the Pretoria district, 17 miles east of the capital, and on washing the surface soil diamonds were soon found. By trenches and bores it was established that a true diamond-bearing volcanic rock or pipe existed here, vertical and of cylindrical shape, filled with a serpentinized peridotite-breccia, identical in every respect with the kimberlite. A little later similar deposits were found on the farm Kaalfontein, next to Rietfontein [501], and on the farms Elandshoek [74] and Franspoort [426].[2] Since then several other diamond pipes have been found in the same area, *e.g.* the Premier Diamond Mine on the farm Elandsfontein [85], which is extremely rich, and probably yields a higher average weight of diamonds per load than any of the diamond mines in South Africa.

All these pipes occur in strata of the Magaliesberg beds, the upper part of the Pretoria series, that is to say, in a formation older than that of the Karroo in which the coal-seams occur. And, as there are no beds older than the Karroo deposits containing a proportion of carbonaceous material, however little, it follows that the carbonaceous constituent, in the form of *diamond*, of the diamond-bearing igneous breccia cannot be attributed to débris from the carboniferous rocks torn from the walls of the pipe by the igneous magma in its upward course.

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[1] D. Draper, **16**, p. 34.

[2] For more details about these formations, see G. A. F. Molengraaff, **37**, p. 144 and **36**; and M. Francke, **21**. *Aanhangsel B.*

These diamond mines of the Transvaal, situated in a deeper geological level than the pipes of Cape Colony or of the Orange River Colony, support the theory that the diamond is a primary constituent of kimberlite. Besides, from the remarkable experiments of Mr. Moissan, it can be deduced that at great depths, in an igneous basic magna, carbon could only crystallize in its densest form, the DIAMOND.

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APPENDIX

During the printing of this memoir, Mr. E. J. Mellor had, on 9th May 1904, communicated to the Geological Society of South Africa a Paper, entitled 'The Waterberg Sandstone Formation and its Relation to other Formations in the Transvaal,' from which an extract reads as follows:—

COMPARATIVE AGE OF THE WATERBERG SERIES

From the considerations detailed above, the conclusion would appear to be fully justified that the age of the Waterberg Formation is very much greater than that of the overlying glacial and coal-bearing strata.

Recent investigations have practically proved the age of the coal-bearing rocks of the Transvaal as Permo-carboniferous. The laying down of the Waterberg rocks must therefore have been considerably earlier than Permo-carboniferous time.

GENERAL SUMMARY

The results arrived at from the consideration of the area described in the present paper may be briefly summarised as follows:—

The base of the Waterberg Formation in the district between Bronkhorst Spruit and Balmoral consists of a well-marked series of conglomerates, breccias, hard purple shales, quartzitic sandstones with magnetite bands, and soft purple-brown sandstones. These are succeeded by an extensive series of brown and purple sandstones, grits, and conglomerates, which form the bulk of the series in most districts where it is at present known.

The Waterberg series, hitherto generally regarded as conformable to the Pretoria series, shows over a considerable area a marked unconformability to the latter. In the most striking instances met with, shown in section (figs. 1 and 2, Plate XII.), rocks of the two series can be seen in contact having almost contrary dips, with a well-developed conglomerate marking the base of the Waterberg Formation.

The shores of the Waterberg sea in the area described consisted largely of Pretoria rocks, the quartzites of which have furnished much of the material for the breccias and conglomerates of the younger series.

The quartzite breccias at the base of the Waterberg Formation at Balmoral were derived directly from the Pretoria quartzites upon which they now lie, and these latter were already of sufficient age to have assumed the character of very hard quartzites, to have suffered considerable movements, and to have formed part of a varied land surface on which the quartzites probably gave rise to prominent features on the shore-line of the sea in which the Waterberg rocks were laid down.

The unconformability of the Waterberg to the Pretoria series, so clearly seen in the district between Balmoral and Bronkhorst Spruit, becomes much less evident west of the latter locality. This is due partly to a local approximation in direction and amount of dip, and partly to extensive igneous intrusions which have apparently followed over considerable distances the approximate junction of the two series.

A large mass of the 'Red Granite,' in the form of a laccolite, has been intruded below the Waterberg series in the neighbourhood west of Balmoral, and has followed for some distance the base of the sedimentary series, the contact with which can be clearly seen.

The glacial conglomerate at the base of the Karroo System has been laid down over large areas on a varied land surface consisting of Waterberg rocks, which still retain clear evidences of glaciation, and which supplied much of the material of the glacial deposits.

The geological changes undergone by the Waterberg series prior to the deposition of the overlying Permo-carboniferous glacial conglomerates point to an age considerably greater than that of the latter rocks.

From similar considerations there must be a very great difference in age between the Pretoria and Waterberg series.

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Molengraaff, G. A. F.
AUTHOR

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